Mulching and tillage with compost to improve poor performing grapevines

by

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DECLARATION

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SUMMARY

The study explored two strategies for improvement of grapevine performance. The first aim was to assess varying levels of compost mulch thickness and the effects thereof on soil water content and grapevine performance as well as to determine whether mulching can be recommended as a water-saving practice under the given conditions. The second aim was to investigate the effect of incorporating organic matter during the root pruning action and with a furrow plough, on the soil environment and grapevine performance. Where spatial variability in sloped or terraced vineyards is a concern, application of compost as a mulch to the grapevine row is impractical. A clear understanding of whether or not incorporating compost proves to have substantial benefits to soil water infiltration and retention, as well as grapevine performance, would be of value to the wine industry. Two methods of organic matter incorporation were compared, namely the furrow plough and deep tillage or root pruning.

In the first experiment, compost mulch was applied on the grapevine row at varying thicknesses in a Shiraz/101-14 Mgt vineyard near Stellenbosch. Results showed that the application of compost mulch to a thickness of 16 cm had no effect on soil water content to a depth of 90 cm compared to the bare soil. While greater fluctuations in soil water content occurred in the 0-30 cm layer, the treatments did not differ with respect to soil water content over the two seasons. However, water infiltration rate increased with mulch thickness, *i.e.* the highest infiltration rate was observed in the soils under the thicker mulches. Nevertheless, the thicker mulches, *i.e.* 8 cm and 16 cm, appeared to intercept rainfall when relatively small events occurred. Under the prevailing conditions, the mulch was not effective in maintaining a higher soil water content on the grapevine row compared to bare soil. Grapevine water constraints were also not affected by compost mulch, regardless of the thickness. However, vegetative growth and yield responded positively to mulch thickness over the two seasons. Since water constraints did not differ in response to mulch thickness, improved water uptake was not considered to have contributed to the improved growth and yield. Fine root development observed in the shallow soil layers under the mulches could have contributed to the growth response by allowing for improved nutrient absorption. The mulch had weathered substantially after two years, which was attributed to the maturity of the compost and the quantity of fine material.

In the second experiment, compost was incorporated using a furrow plough during the root pruning action, and compared to a no-till and no compost control, as well as root pruning without compost. The treatments were applied in every, and in alternate rows in a terraced Pinotage/R110 vineyard near Stellenbosch. Compost incorporation by means of the furrow plough and root pruning, increased water infiltration rate compared to the control. Root pruning without compost also tended to increase infiltration rate. Higher infiltration rates are expected to reduce water loss by runoff and increase in the amount of water entering the soil. However, the tillage and compost treatments had no effect on the soil water content on the grapevine row. It would seem that there was limited lateral flow of water from the work row to the grapevine row. After two years, the furrow plough with compost and root pruning with and without compost reduced penetration resistance up to 15 cm and 45 cm, respectively. The lower penetration resistance in the soil where compost was incorporated using the furrow plough could be attributed to a slightly higher soil water content in that layer where the compost was concentrated. The penetration resistance in the soil of the control exceeded the 2000 kPa threshold for inhibited root growth at a depth of 12 cm. The soil loosening action of the root pruning with compost is expected to allow for improved root development to a greater depth than the furrow plough treatment. However, the furrow plough treatment may have encouraged root development between the tractor wheel tacks to a depth of 15 to 20 cm. Root pruning per *se* had no

effect on the soil chemical status, but decreased compaction. Where compost was added, the soil pH increased, probably due to the high amount of calcium in the compost and the dissolution of organic acids present in the organic material. The compost also tended to increase magnesium, potassium and sodium as well as organic carbon and phosphorus in the soil, particularly in the shallow layers. The potassium and phosphorus could be a source of nutrients to the grapevines, while the organic carbon influences the accumulation of soil organic matter. Although the amount of sodium in the soil increased, the extractable sodium percentage was in fact reduced in the 0-15 cm soil layer, due to the high amount of calcium. The extractable sodium percentage was also well below the threshold where sodicity problems would be expected.

Under the prevailing conditions, root pruning did not seem to have a positive effect on grapevine vegetative growth and yield. Rainfall during the study was appreciably lower than the long term mean, particularly in 2015. As a result of dry soil conditions the degree of root regeneration in the loosened soil and the subsequent grapevine responses may have been affected. In contrast, where compost was incorporated during the root pruning action, growth and yield increased over two consecutive seasons. Likewise, where compost was incorporated in furrows, it also had a positive effect on growth and yield. It appeared that root pruning in every row with compost did not provide significant additional benefits to growth and yield compared to the root pruning in alternate rows with compost. Apart from the slightly higher pH and lower colour in the wines of the compost treatments in the first year, juice and wine quality characteristics were not affected by any of the tillage or compost treatments. The higher potassium content in the soils measured two years after the compost was applied appeared to have had no effect on juice and wine quality. Cover crop growth also responded positively to the addition of compost. It is interesting to note that the enhanced cover crop performance did not appear to compete with the grapevines. Decomposition and mineralisation of the cover crop residue in the vineyard would be expected to further improve organic matter and nutrient accumulation in the soils where cover crop dry matter production was high.

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OPSOMMING

Die studie het twee strategieë ondersoek vir die verbetering van wingerdstokprestasie. Die eerste doelwit was om wisselende diktes komposdeklaag en die effekte daarvan op grondwaterinhoud te meet en wingerdprestasie, sowel as te bepaal of deklae aanbeveel kan word as 'n waterbesparingspraktyk in die heersende omstandighede. Die tweede doel was om die effek van organiese materiaal wat tydens ‘n wortelsnoei aksie of met 'n vlekploeg ingewerk is, op die grondomgewing en wingerdstokprestasie te ondersoek. Waar ruimtelike variasie in skuins of geterrasseerde wingerde groot is, is die toediening van ’n komposdeklaag op die wingerdstokry onprakties. 'n Beter verstaan van die inkorporering van kompos aansienlike voordele inhou vir grondwater infiltrasie en -behoud, asook wingerdprestasie, sou waarde inhou vir die wynbedryf. Twee metodes van organiese materiaal inkorporering is vergelyk, naamlik die vlekploeg en diepbewerking of wortelsnoei.

In die eerste eksperiment is ’n komposdeklaag toegedien op die wingerdstokry teen verskillende diktes, in 'n Shiraz/101-14 Mgt wingerd naby Stellenbosch. Resultate het gewys dat die toediening daarvan op die wingerdstokry tot 'n dikte van 16 cm geen effek op grondwaterinhoud gehad het tot 'n diepte van 90 cm, in vergelyking met kaal grond. Groter skommelinge in grondwaterinhoud het in die 0-30 cm laag voorgekom, maar die behandelings het nie verskil met betrekking tot grondwaterinhoud oor die twee seisoene nie. Water infiltrasietempo het egter toegeneem met deklaagdikte, d.w.s. die hoogste infiltrasietempo was in die gronde met dikker deklae waargeneem. Nietemin, die dikker deklae, d.w.s. 8 cm en 16 cm, het oënskynlik reënval onderskep wanneer dit min gereën het. Onder die heersende omstandighede was die deklaag nie effektief in die handhawing van 'n hoër grondwaterinhoud op die wingerdstokry, in vergelyking met kaal grond nie. Wingerdstok watertekorte was ook nie beïnvloed deur die kompos deklaag nie, ongeag die dikte. Vegetatiewe groei en opbrengs het egter positief reageer op deklaag dikte oor die twee seisoene. Aangesien watertekorte nie reageer het op deklaagdikte nie, is dit onwaarskynlik dat beter wateropname bygedra het tot die beter groei en opbrengs. Fynwortelontwikkeling wat in die vlak grondlae onder die deklae waargeneem is, kon bygedra het tot die groeireaksie deur beter voedingstofopname te fasiliteer. Die deklaag het kwaai verweer na twee jaar, wat aan die volwassenheid van die kompos en die hoeveelheid fyn materiaal toegeskryf kan word.

In die tweede eksperiment, is kompos ingewerk met behulp van 'n vlekploeg tydens ’n wortelsnoeiaksie, wat vergelyk is met geen bewerking en geen kompos byvoeging, asook wortelsnoei sonder kompos. Die behandelings is in elke, asook in alternatiewe rye in 'n geterrasseerde Pinotage/R110 wingerd naby Stellenbosch toegepas. Kompos inkorporering met ’n vlekploeg en tydens wortelsnoei, het waterinfiltrasietempo verhoog in vergelyking met die kontrole. Wortelsnoei sonder kompos het ook geneig om infiltrasietempo te verhoog. Hoër infiltrasietempos kan moontlik waterverlies deur afloop verminder en grondwaterinhoud verhoog. Die bewerking en komposbehandelings het egter geen effek op die grondwaterinhoud gehad op die wingerd ry. Dit lyk asof daar beperkte laterale vloei van water vanaf die werkry na die stokry was. Na twee jaar het die vlekploeg met kompos en wortelsnoei met en sonder kompos die grondpenetrasieweerstand tot op dieptes van 15 cm en 45 cm onderskeidelik verminder. Die laer penetrasieweerstand in die grond waar kompos geïnkorporeer is met behulp van die vlekploeg kan moontlik toegeskryf word aan 'n effens hoër grondwaterinhoud in die laag waar die kompos gekonsentreer was. Die penetrasieweerstand in die grond van die kontrole het die 2000 kPa drempelwaarde vir optimale wortelgroei op 'n diepte van 12 cm oorskry. Dit was verwag dat die grondlosmaakaksie van die wortelsnoei met kompos beter wortelontwikkeling tot 'n groter diepte sou toelaat as die vlekploeg behandeling. Die vlekploeg behandeling het egter wortelontwikkeling tussen die trekker wiel spore

aangemoedig tot 'n diepte van 15 tot 20 cm. Wortelsnoei het geen effek op die grond chemiese status gehad nie, maar grondkompaksie het afgeneem. Waar kompos ingerwerk is, het die grond pH toegeneem, waarskynlik as gevolg van die hoë inhoud van kalsium in die kompos en die ontbinding van organiese sure in die organiese materiaal. Die kompos was ook geneig om magnesium, kalium en natrium asook organiese koolstof en fosfor in die grond te vermeerder, veral in die vlak grondlae. Die kalium en fosfor kan 'n bron van voedingstowwe vir die wingerdstokke wees, terwyl die organiese koolstof die aansameling van organiese materiaal beïnvloed. Hoewel die hoeveelheid natrium in die grond verhoog het, het die ekstraheerbare natriumverhouding verminder in die 0 15 cm grondlaag as gevolg van die hoë vlakke van kalsium. Die ekstraheerbare natriumverhouding ontledings was ook goed onder die drempel waar natriumbrak probleme verwag sou word.

In die proef kondisies het wortelsnoei nie 'n positiewe uitwerking op wingerd vegetatiewe groei en opbrengs gehad nie. Reënval tydens die studie was merkbaar laer as die langtermyn gemiddelde, veral in 2015. As gevolg van droë grondtoestande, kon die graad van wortelgroei in die los grond en die daaropvolgende wingerd reaksies beïnvloed gewees het. In teenstelling, waar kompos geïnkorporeer was gedurende die wortelsnoei aksie, het groei en opbrengs oor twee opeenvolgende seisoene verhoog. Net so, waar kompos geïnkorporeer is in vlekvore, was daar ook 'n positiewe effek op groei en wingerd opbrengs. Dit lyk nie asof wortelsnoei in elke ry met kompos aansienlike bykomende voordele tot groei en opbrengs gehad het nie, in vergelyking met wortelsnoei in alternatiewe rye met kompos. Afgesien van die effens hoër pH en laer kleur in die wyne van die komposbehandelings in die eerste jaar, was sap en wyngehalte eienskappe nie geraak deur enige van die bewerking of komposbehandelings nie. Die hoër kaliuminhoud in die grond twee jaar nadat die kompos toegedien was het ook geen merkbare effek op sap en wyngehalte gehad nie. Dekgewas groei het ook positief reageer tot die byvoeging van kompos. Dit is merkwaardig dat die verbeterde dekgewasprestasie waarskynlik nie met die wingerdstokke kompeteer het nie. Waar degewas groei goed was, sou afbraak en mineralisasie van die dekgewasreste in die wingerd waarskynlik organiese materiaalinhoud en voedingstofaansameling verder verbeter.

This thesis is dedicated to my family for their support and encouragement

BIOGRAPHICAL SKETCH

Emma Moffat was born in Cape Town on 11 May 1985. She matriculated at Herschel Girls' High School in 2003. Emma enrolled at Stellenbosch University in 2004 and obtained the degree BScAgric in Viticulture and Oenology in December 2007. After working in the wine industry as a winemaker in Stellenbosch for five years, she enrolled for the MSc. Agric. in Viticulture degree in 2015 at Stellenbosch University.

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PREFACE

This thesis is presented as a compilation of six chapters. Each chapter is introduced separately and is written according to the style of the South African Journal of Enology and Viticulture.

Chapter I	**General introduction and project aims**
Chapter II	**Literature review** Mulching and tillage with compost to improve poor performing grapevines
Chapter III	**Research results** The effect of compost mulch thickness on soil water conservation and grapevine performance
Chapter IV	**Research results** The effect of root pruning with compost incorporation and the furrow plough with compost on soil conditions
Chapter V	**Research results** The effect root pruning with compost incorporation and the furrow plough with compost on grapevine performance and cover crop growth
Chapter VI	**General conclusions and recommendations** Mulching and tillage with compost to improve poor performing grapevines

CONTENTS

Chapter 1

Introduction and project aims

CHAPTER I: INTRODUCTION AND PROJECT AIMS

1.1 Introduction

Given the anticipated climatic change, concern about water availability and the gradual degradation of soils, emphasis must be placed on developing, and validating management practices to optimise vineyard performance under changing circumstances an at different sites. These practices should also be aimed at improving poor performing or patchy vineyards for productivity and economic sustainability.

The need to conserve soil water is becoming increasingly important in South Africa, particularly in existing dryland vineyards. The positive effects of straw mulches in terms of water-saving (Myburgh, 2013) and improved infiltration, reduced runoff and erosion have previously been shown (Louw & Bennie, 1991). Compost mulch has been reported to increase yields in low yielding areas under high mulch rates but can also increase berry potassium and pH (Chan *et al.* 2010). Although the potassium and pH responses could be linked to compost quality and composition, research is still needed to quantify the effects of compost mulch thickness on potential water saving and subsequent grapevine performance. While compost application may entail immediate costs, the long-term financial benefits can be significant, as well as the benefits to the soil environment. The first part of the study will investigate the effects of a compost mulch on soil water-related properties, the possible water-saving implications thereof, as well as the effect of mulch on grapevine growth, yield and berry quality under dryland conditions.

Variability in vineyards is common throughout the winegrowing regions of the world. This creates numerous challenges for growers since it can increase production costs. Therefore, it is important for growers to be able to apply effective practices aimed at enhancing poor performing sections within variable vineyards. In this regard, practices such as root pruning, which targets soil physical limitations, and organic amelioration, which addresses soil physical as well as chemical constraints could be of value, particularly where both can be applied in one action. The pruning of roots when soil compaction is alleviated, can stimulate the formation of new roots. This will improve grapevine performance in terms of yield and vegetative growth but there is some debate around the regenerative ability of older roots (Geisler & Feree, 1984) and whether or not it is an effective practice for long term improvement. Current knowledge on grapevine root pruning in South Africa is based mostly on growers' practical experience and information derived from a limited number of field trials where root system observations were made. Several studies have been carried out on apple and peach trees, but usually with the aim of reducing vegetative growth (Ferree & Rhodus 1993). However, studies with grapevines have shown that root pruning on one side, two weeks before budburst, reduced vegetative growth, but increased the yield of Shiraz (Dry *et al*., 1998). It was also shown that regular, severe root pruning when combined with a cover crop had a negative effect on yield and growth of irrigated, ungrafted Colombar (Saayman & Van Huyssteen, 1983). Therefore, further research evaluating the practice of root pruning on different soils at varying rates of severity is required.

Soil organic matter plays a vital role in soil fertility and soil health. Organic matter can improve soil structure, reduce bulk density, increase water holding capacity and soil water content as well as modify pH (Tester, 1990). Furthermore, it may enhance microbial and macro-fauna activity such as earthworms, nematodes and insects. The loss of organic matter has a significant effect on the soil environment, including soil structure and infiltration, water holding capacity and nutrient supply (Mills & Fey 2003). These factors play a crucial role in maintaining a healthy soil environment for root growth. Humic and fulvic acids, *i.e.* the end-products of compost decomposition, as well as fungal threads and polysaccharides are important for maintaining aggregate stability (Cass & McGrath, 2004). Based on the foregoing positive effects, the incorporation of organic matter could enhance the effect of root pruning in poor performing vineyards or patches. However, there is limited scientific information regarding the effects of organic matter incorporated during root pruning. Therefore, the second part of the study intends to explore the effects of root pruning with compost incorporation on the soil environment, root growth and above-ground grapevine performance under dryland conditions. If this practice proves to be successful, it would establish the ground work for further investigation into the costs, as well as the most efficient implements to incorporate compost during root pruning.

The significance of this study for the research community is to provide scientific information on root pruning as a management practice and to determine whether or not it can be implemented in combination with compost to boost grapevine performance. The grape/wine industry will benefit from this information given that vineyard variability is a widespread concern for growers, as well as water availability. Where spatial variability in sloped or terraced vineyards is a concern, application of compost to the grapevine row is impractical. A clear understanding of whether or not, incorporating compost proves to have substantial benefits to soil water infiltration and retention, as well as grapevine performance, would be of value to the wine industry.

1.2 Project Aims

The aims of this study were to:

2.2.1 Assess varying levels of compost mulch thickness and identify the ideal mulch rate at which water-saving benefits are realised if any

2.2.1.1 Compare the effects of different compost mulch rates on soil water content

2.2.1.2 Evaluate the effect of mulch thickness on grapevine performance

2.2.2 Investigate the effect of incorporating organic matter during the root pruning action and with a furrow plough, on the soil environment and grapevine performance

2.2.2.1 Evaluate the effects of root pruning without compost, root pruning with compost incorporation and the furrow plough on soil conditions and the alleviation of possible limiting soil properties

2.2.2.2 Compare two methods of compost incorporation i.e. root pruning and the furrow plough

2.2.2.3 Evaluate the effects of root pruning with and without compost, and the furrow plough on grapevine performance

1.3 References

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Chapter 2

Literature review

Mulching and tillage with compost to improve poor performing grapevines

CHAPTER II: MULCHING AND TILLAGE WITH COMPOST TO IMPROVE POOR PERFORMING GRAPEVINES

2.1 Introduction

Variability in vineyards is common throughout the grape-growing regions of the world, and presents numerous challenges for growers when it comes to securing desirable yields and consistent quality. The financial and environmental implications of applying management practices and inputs uniformly across vineyard blocks are plain and this nature of farming is increasingly considered unsustainable. The development of Precision Viticulture, however, and the various forms of technology supporting it aims to enable researchers and growers to better understand and identify variable zones within a block and apply inputs differentially and more efficiently. While technologies such as remote sensing, yield mapping and high resolution soil surveys have been successfully used to characterize zones within vineyards, they are not yet widely accessible to growers but are expected to become so, as the technology develops and becomes more affordable. Spatial variability in grapevine performance may be assessed in terms of grapevine vigour, yield or fruit composition and quality. There are various key factors driving spatial variability such as variation in soil physical, chemical and biological properties, which are typically linked to topography. Knowledge thereof enables growers to apply focused management practices to specific zones or parcels within a block, which means better control over grapevine performance and quality.

While there is much debate about global warming and the causes of climate change, changing climate patterns in South Africa is a reality. Changing rainfall patterns, temperature and relative humidity are of particular concern to the wine industry. With increased concern about future water availability, management practices that enable growers to adapt to changing weather patterns have become critical for the sustainability of vineyards, in particular dryland vineyards. In the Western Cape, districts such as Malmesbury, Stellenbosch and Paarl, are home to some of the oldest dryland vineyards in South Africa. While yields are typically lower than most irrigated vineyards, many of these vineyards have produced high quality grapes destined for high-end wine labels for many years.

Conventional management practices aimed at improving grapevine performance, whether in a localized area within a block or an entire vineyard, are focused on short-term solutions such as fertilizer inputs and intensive cultivation. Sustainable grape production requires long-term solutions that improve soil health and not only productivity. By and large, disparities in grapevine performance are linked to limited soil water availability, either due to poor exploitation of the soil water reserve by the root system or limited soil water-holding capacity. Where soil chemical status is the limiting factor, fertilizers can be easily applied but have limited benefits for soil health. The concept of soil health has been defined as “the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans” (USDA, 2012). To ensure future sustainability of South Africa’s drier viticultural regions, it is imperative that growers look to the implementation of management practices that endeavour to improve soil health in the long term, for sustained productivity. Compost incorporation during root pruning or by means of the furrow plough as well as mulching on the grapevine row three such potential management practices.

2.2 Soil and grapevine responses to organic matter mulches.

The application of compost, green waste, crop residues, straw and plastic mulches are management practices aimed at improving water use efficiency and soil fertility, inhibiting weed growth and promoting soil biological activity. Mulches may also be employed to address vigour variability within vineyards, which is often caused by inadequate water supply to grapevines and/or unfavourable soil conditions. Current climate conditions point towards water becoming a major limiting factor in grapevine growth and mulches are perceived to contribute to water conservation. Mulch can be applied in various forms, including living ground cover and organic or inorganic materials applied to the soil surface. Organic mulches may comprise crop residues, bark, straw and compost derived from green waste such as grapevine prunings. Reported benefits of mulch include reduced water losses (Chan *et al.*, 2010; Myburgh, 2013), reduced erosion and runoff (Louw & Bennie, 1991; Prosdocimi *et al*., 2016), reduction in daily temperature ranges (Chan *et al*., 2010) as well as increased soil porosity, moisture retention and aggregate stability (Mulumba & Lal, 2008; DeVetter *et al*., 2015).

2.2.1 Effect on soil conditions

2.2.1.1 Infiltration and soil water content

Perhaps the most important effect of mulch is its impact on soil physical properties, as the soil physical status governs the soil's ability to retain water, soil conditions for biological activity and root development. The prevention of water loss by runoff and erosion is of particular importance in semi-arid and arid wine-growing regions. The contribution of no-till systems, crop residues and mulches to soil properties which reduce erosion and runoff, is well documented (Mulumba & Lal, 2008; Jordán *et al.*, 2010). In addition to protecting the soil surface from raindrop impact, mulches improve physical soil structure near the soil surface, enabling improved infiltration. It was reported that 4 t/ha wheat straw mulch increased soil porosity and 8 t/ha increased aggregate stability and soil water retention (Mulumba & Lal, 2008).

In a study comparing minimum and conventional tillage practices, annual full-surface application of straw mulch was the most effective in conserving winter-stored soil moisture compared to clean cultivation and a permanent cover of indigenous weeds cut by a bush-cutter, in a Chenin blanc/101-14 Mgt vineyard near Stellenbosch (Van Huyssteen & Weber, 1980b). Where weeds were controlled by herbicide in the same study, the undisturbed soil surface with residue acted as a mulch and also conserved water compared to clean cultivation and permanent weed cover. In a study comparing compost comprising sewage sludge plus bark and municipal waste compost to a control and a black polyethylene film, both compost mulches reduced evaporation and improved soil water retention capacity (Pinamonti, 1998). In contrast, where compost from garden and food waste was applied on the grapevine row up to 5 cm, soil water content (SWC) was only increased at the 10 cm soil depth during dry and wet periods, whereas incorporated compost (100 m^3/ha) had no effect on soil water content compared to the unamended control (Nguyen *et al*., 2013). The reason for the lack of differences in soil water content (SWC) in the previously mentioned trial could be that irrigation prevented the deeper soil layers from drying out. Since water is a limited resource, practices that can reduce water loss by evaporation are of particular importance to growers with restricted water access. It was shown that wheat straw mulches of 4 t/ha, 8 t/ha and 12 t/ha reduced water loss during the initial evaporation stage compared to bare soil and shallow tillage in a 12-year-old Sauvignon blanc/R99 vineyard near Stellenbosch (Myburgh, 2013). Furthermore, the cumulative water losses decreased with an increase in mulch thickness. Therefore, straw mulch would be more beneficial under conditions of frequent irrigation than under low frequency irrigation. These findings are supported by those of Ji and Unger (2001), in which straw mulch increased storage of soil water from small precipitation events despite the fact that evaporation rates were higher for mulched soil compared to bare soil during the late stage. Similar results were found for bark and vine residue mulch and plastic mulch compared to bare soil and geotextile mulch (Zribi *et al*., 2015). Where compost mulch was applied up to 15 cm on the grapevine row at several sites, soil moisture depletion was appreciably delayed compared to bare soil (Agnew *et al*., 2002). However, the positive effect of mulching on soil water retention differed among the different soil types with more variable effects on the lighter soils.

2.2.1.2 Soil temperature

Organic mulches have been shown to reduce soil temperature fluctuations (Pinamonti, 1998; Agnew & Mundy, 2002; Fourie & Freitag, 2010) whereas plastic mulches can result in higher soil temperatures (Bowen *et al*., 2003; Moreno & Moreno, 2008). It was previously shown that on a medium textured soil, full surface straw mulch could give rise to sub-optimal temperatures which can affect bud break and microorganism activity but was effective in lowering soil temperature during the season (Fourie & Freitag, 2010). Furthermore, soil temperature under the straw mulch did not exceed 25-30°C, the threshold for inhibited plant growth (Kliewer, 1975). Chan *et al*. (2010) showed that mulch application reduced the daily temperature range at a depth of 10 cm in several vineyard soils. Kliewer (1975) demonstrated that root temperature plays a significant role in bud break, shoot growth and development of fruit clusters and that root temperatures above 35°C reduced growth of shoots, leaves and fruit clusters.

2.2.1.3 Soil organic matter and microbial activity

Many of the mulch-induced changes in soil physical properties such as aggregate stability, infiltration, porosity, water-holding capacity are influenced by the accumulation of soil organic matter (SOM) under mulch. While the contribution of organic mulches to SOM content is slow, several studies have demonstrated increases in OM content of soils treated with wheat straw mulches (Blanco-Canqui & Lal, 2007; Jordán *et al.*, 2010). Such changes are often limited to surface layers, as illustrated in a study where wheat straw mulch resulted in an increase in soil organic carbon (SOC) and total soil N content in the top 5 cm soil layer (Saroa & Lal, 2003).

While significant effects on the soil chemical status have rarely been reported, De Vleeschauwer *et al*. (1978) noted a significant effect of mulching on the potassium content of soil under rice straw mulch after 13 months. It appears as if the contribution of mulches to soil chemical status is largely dependent on the composition of the mulch material applied. In a trial carried out in Italy with two composts comprising of (i) sewage sludge with bark, with a low metal content and (ii) municipal soil waste with a higher metal content, both mulches increased soil exchangeable K, available P, OM, porosity and water retention capacity (Pinamonti, 1998). The compost with the higher heavy metal concentration also led to an accumulation of metals in the soil as well as in the vegetative parts of the grapevine and musts, although no toxicity symptoms were recorded.

The effect of mulch application on the microbial status of soil is not well-documented. The dynamic nature of soil microbial populations and their fluctuations in activity due to various environmental factors makes it difficult to obtain clear, meaningful results in this regard. Organic mulches are also variable in their composition and C:N ratios, and can therefore be variable in their effect on microbial community structure and the mineral status of soils. Forge *et al.* (2003) reported an increase in protozoan and bacterivorous nematode populations in an apple orchard under organic mulches consisting of shredded paper, municipal biosolids and green waste compost compared to plastic mulch and herbicide managed tree rows. It was also previously demonstrated that nutrient cycling was greater under these organic mulches. Protozoa and bacterivorous nematodes stimulate microbial turnover and mineralisation. In the previously mentioned study, nematode communities were used as indicators of the condition of the soil food web. Through decomposition of SOM, microbes enhance availability of nutrients such as nitrogen (N), phosphoros (P) and sulfur (S) to plant roots, while also contributing to the source of N that can be mineralized in soils. Where OM derived from mulching does contribute to the SOM content, it's most significant contribution may be the maintenance of favourable soil environmental conditions in which microbes may flourish, *i.e.* preserved soil moisture and reduced temperature fluxes.

2.2.2 Grapevine responses

2.2.2.1 Plant water status

The ability of various organic mulches to conserve soil moisture, reduce evaporative losses and improve soil water holding capacity is well-documented (Van Huyssteen & Weber, 1980b; Pinamonti, 1998; Nguyen *et al*., 2013). Grapevine water status is influenced primarily by soil type, soil water content, environmental factors such as relative humidity, temperature and wind, as well as cultivar attributes (Taylor *et al*., 2010). Reduced evaporation and improved water holding capacity under mulches are expected to limit severe grapevine water constraints by buffering the grapevine against water stress. There are few studies in which grapevine response in terms of plant water status has been evaluated in conjunction with soil moisture. One such study showed that midday stem water potential was not affected by a compost mulch, however no differences in SWC were observed (Nguyen *et al*., 2013). Where root systems have access deep soil water reserves, the grapevine's response in terms of water stress to mulch will be limited. Where a full surface straw mulch was applied, mulches of 4 to 12 t/ha had no effect on midday leaf water potential, except for a lower leaf water potential observed under the thickest mulch during véraison (Myburgh,2013).

2.2.2.2 Root growth

Research on the effect of compost mulch on root dynamics is limited but several studies have shown greater abundance of roots at shallow depths under mulches (Van Huyssteen & Weber, 1980c; Pinamonti 1998; Agnew *et al.*, 2002). Organic mulch may encourage root growth near the soil surface due to higher soil water content, reduced temperature fluctuations, slow release of nutrients near the soil surface, as well as reduced compaction.

2.2.2.3 Vegetative growth

Apart from canopy size manipulation during pruning and summer canopy management, vegetative growth is affected by water (Van Huysteen & Weber, 1980c), nutrient availability (Conradie, 2001), ambient temperature and humidity (Buttrose, 1968) as well as rootstocks and root growth. Mulches may have an effect on grapevine vigour *via* their influence on soil water content as well as nutrient release. Van Huyssteen and Weber (1980c) compared shoot length and pruning mass of grapevines under minimum and conventional tillage treatments. Their results showed that full surface straw mulch had a positive effect on the rate of shoot growth and on mean pruning mass compared to clean cultivation, shallow and deep trench furrow systems and permanent weed growth cut by brush-cutter. In contrast, Nguyen *et al*. (2013) found that 5 cm thick compost mulch from garden and food waste did not have a significant effect on shoot growth when applied to the grapevine row. Similarly, full surface straw mulch, regardless of thickness, had no effect on grapevine pruning mass compared to bare untilled soil (Myburgh, 2013). In a field trial carried out over five years, two organic mulches consisting of sewage sludge plus bark, and municipal waste had a positive effect on pruning weight in the first year after application only, despite re-application of the organic mulch in the third year (Pinamonti, 1998).

2.2.2.4 Yield and its components

It would seem that grapevine yield response to mulches is variable and dependent on factors such as mulch rate, mulch composition and existing soil conditions. Van Huyssteen and Weber (1980b) examined the effects of various tillage systems, including shallow and deep trench furrow, straw mulch cover, herbicide, clean cultivation and permanent sward, on grapevine performance. It was concluded that the straw mulch treatment resulted in higher grapevine yields compared to the control and other treatments. The response of grapevine performance to mulches is likely to be dependent on the degree to which the mulches improve soil conditions. This was shown in a study where increased grapevine yield occurred only where composted mulch had been applied at a high rate (153 m^3/ha) in lower yielding areas of a vineyard (Chan *et al*., 2010). The higher yield in response to mulch in the aforementioned study was related to increased soil moisture, lower soil temperature fluctuations and reduced weed competition. In contrast, Mugnai *et al*. (2012) found that the yield response to 15 t/ha green waste compost applied annually to Chardonnay, varied over a 9-year period despite having a positive effect on soil pH, OM, N and suppressive effect on soil nitrate levels.

2.2.2.5 Juice and wine characteristics

The effect of mulch on juice and wine characteristics is not well documented but appears to be relatively variable as is the case for grapevine yield, and may be linked to mulch composition. When compost is applied, an oversupply of soil K^+ can occur, which can have unfavourable effects on juice and wine quality such as increased wine pH, particularly where grape marc makes up a large portion of the compost material. In some cases where mulch effects on grape, must and wine quality have been evaluated, increased K^+ concentrations of grapes (Chan & Fahey, 2011) and must (Pinamonti, 1998) have been observed, whereas rates of 4 to 12 t/ha full surface straw mulch had no effect on juice quality characteristics (Myburgh, 2013). Where Chan and Fahey (2011) observed increased berry K^+ and small increases in berry pH in response to mulch, it was dependent on mulch rate (153 m^3/ha) and the season. Interestingly, in another study where compost mulch increased juice K^+ levels, no differences in juice pH and titratable acidity (TA) were observed (Pinamonti, 1998). In a previous study, full surface straw mulch tended to increase juice total titratable acidity (TTA) and resulted in higher quality wines compared to permanent sward (Van Huyssteen & Weber, 1980c). In New Zealand, where a 15 cm mulch was applied on the grapevine row at several sites, the effect of site and season on juice K^+ levels was greater than that of the mulch (Agnew *et al*., 2002). Therefore, the effects of mulch on grape and wine composition appear to be variable and dependent on mulch rate, mulch composition and soil type or vineyard location.

2.3 Soil tillage practices to enhance grapevine performance

2.3.1 Root pruning

Root pruning is a horticultural practice that has been applied to fruit trees, bonsai’s and in forestry nurseries as a means to control growth and yield of woody plants (Geisler & Feree, 1984; Van Zyl & Van Huysteen, 1987). The response of plants to root pruning is dependent on the timing and severity of the root pruning action, and soil conditions such as water and nutrient availability. Current knowledge on grapevine root pruning in South Africa is based mostly on growers’ practical experience and information derived from a few field trials where root system observations were made. By and large, root pruning in South Africa was carried out when existing vineyards were ripped in order to alleviate compaction and improve above-ground growth. By pruning roots, regeneration of new roots occurs near the severed tips (Van Zyl & Van Huysteen, 1987). The intention of root pruning in such cases is to stimulate root regeneration to increase capacity for aerial growth. This includes the elongation of existing unpruned roots and the stimulation of new lateral and fine roots with subsequent elongation. The relationship between root volume and aerial growth has previously been illustrated (Morlat & Jacquet, 1993; Mcartney & Ferree, 1999) as well as the effect of increased soil depth on shoot growth and yield (Saayman & Van Huysteen, 1980). In a previous study, it was shown that vegetative growth of young Shiraz grapevines decreased with a reduction in available soil volume, but where soils were subjected to deep ripping and the available soil volume was unconfined, grapevine pruning weight was comparable to that of grapevines subjected to the smallest available root volume (McClymont *et al.*, 2006). The negative response of vegetative growth to an unconfined available soil volume in the aforementioned study was considered a result of water stress early in the season where deep ripping had occurred. Therefore, it is critical that root pruning be carried out under conditions of adequate soil moisture, preferably just before the winter rainfall or in spring when stored soil moisture is still sufficient.

2.3.1.1 Implements

Root pruning was traditionally done using single tine rippers (Van Huyssteen & Saayman, 1980). However, the rippers were found to be ineffective due to the tractor requirements as well as wheel-slipping which caused further compaction. Later, the German wiggle plough or “wikkelploeg” was introduced but experienced difficulty penetrating some South African soils and generated much vibration which was transmitted to the tractor (Van Huyssteen & Saayman, 1980). Modifications were subsequently made to the implement in order to overcome these problems, which led to a locally developed model “wiggle plough” although commercial availability was limited.

In South Africa, mechanical compaction is a common occurrence in vineyards managed by conventional tillage. The use of tractors causes compaction in the tractor wheel tracks and repetitive action of implements compresses soil to the working depth and can result in a ploughpan (Van Huysteen, 1988). Silt and clay particles are washed downwards and deposited into pores of the subsoil. Under dryland conditions, particularly where the soil is bare, surface crusting limits infiltration and increases precipitation runoff (Van Zyl & Van Huyssteen, 1983). It was thought that compaction needed to be alleviated in the tractor wheel track but it was subsequently shown that compaction in this zone quickly re-occurs (Van Huyssteen, 1986). In deep soils roots are able to grow underneath the wheel compaction zone, whereas in shallow soils where roots are unable to penetrate below the compacted tractor wheel track zone, the regenerative ability of pruned roots is diminished. Root pruning should therefore be applied between the tractor tire tracks where re-compaction will not occur (Van Zyl & Van Huyssteen, 1987).

2.3.1.2 Timing

Van Zyl (1984) demonstrated that grapevine roots have two peak periods of active growth, namely after bud break until flowering and after harvest (Fig.2.1). These findings are supported by Conradie (1980). In contrast, root growth mainly occurred between flowering and véraison in temperate and Mediterranean climates, despite the concurrent summer growth (Comas *et al.*, 2010). Nevertheless, root pruning in South Africa is typically carried out once every five years during the post-harvest period in autumn when the regenerative ability of roots is considered optimal (Van Huyssteen, 1981). However, during dry years or when rain only occurs late in winter, soil conditions will not be suitable for deep tillage. In such cases, root pruning may be done before bud break.

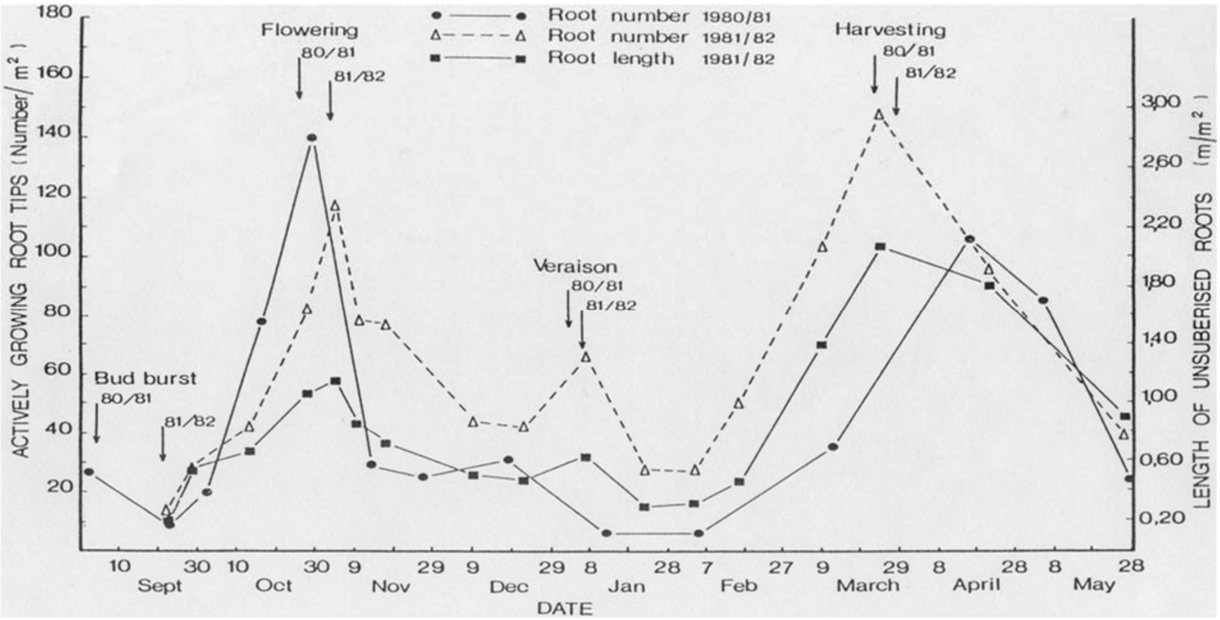

Figure 2.1. The periods of active root growth of Colombar/99R over two seasons (Van Zyl, 1984).

2.3.1.3 Root responses

Roots systems fulfil a number of vital functions for the plant such as anchorage, storage of nutrients and accumulated carbohydrates, supply of growth hormones, production of organic compounds and uptake of water and nutrients (Kramer, 1983; Jackson, 2008). Since root functioning is difficult to study without carrying out destructive measurements, much about the grapevine root system's functioning and root factors governing aerial growth is unknown. What is apparent is that the function, efficiency and lifespan of individual roots is partly determined by root order, age and location within the root system. It has been reported that the capacity of apple and citrus trees for phosphorous uptake is dependent on root age (Bouma *et al.*, 2001). In the same study, it was discovered that changes in root physiology and soil characteristics governing the rate of nutrient depletion in the rhizosphere are equally important in determining the age at which a root reaches maximum efficiency. This could play a significant role in understanding a positive growth response to root pruning with compost, if root growth is stimulated.

Apart from the phenological stage, the regenerative ability of roots is influenced by environmental factors, the timing and severity of the root pruning action, as well as grapevine age and root thickness. According to Geisler and Ferree (1984), warm temperatures, adequate aeration and the absence of water stress are conducive to root regeneration. It is also likely that different rootstocks could respond differently to root pruning. In a previous study, it was shown that the regeneration of thicker roots of Chenin blanc/99R was better than that of thinner roots but this relationship was not observed for Sultanina in a separate study (Van Zyl & Van Huyssteen, 1987). Although Geisler and Ferree (1984) refer to younger plants demonstrating a better response to root pruning than older plants, root pruning studies are limited and have not thoroughly explored this aspect of root development.

Grapevine roots of different ages and sizes differ in their functions. Fine roots, in particular, are important for water and mineral nutrient uptake. There are several mechanisms and processes by which plants obtain nutrients from the soil. A small percentage of nutrients are taken up through interception of mineral ions by roots and mass flow. Diffusion, whereby nutrients are transported in the soil to the root surface, plays a larger role in nutrient uptake. Transport of nutrient ions is driven by osmotic potentials. As the plant transpires, water moves *via* convective flow through the soil towards the roots by mass flow, which is responsible for transport of Ca^{2+}, Mg^{2+} and NO_3^-. Both mechanisms depend on water as well as nutrient concentrations in the soil. Furthermore, it has been found that only newly expanding, unsuberized root caps can absorb nutrients such as Ca^{2+} and, to a lesser degree Mg^{2+} and Fe^{2+}, which means that active root growth is necessary for sufficient uptake of these nutrients. Other biological factors, such as the presence of mycorrhizal fungi, have been shown to play a significant role in the uptake of nutrients by the roots, in particular the uptake of P where P levels in the soil are low (Schreiner, 2007).

2.3.1.4 Growth and yield responses to root pruning

Grapevine water constraints are influenced by transpiration rate, the relationship between stem water potential and SWC and the rate of movement of water from the soil to the roots (Kramer, 1983). Since studies on root pruning under South African conditions are limited, the effect of root pruning on grapevine water constraints has not been evaluated. The removal of a portion of a plant root system and the subsequent decline in absorption is likely to cause a degree of water stress (Geisler & Ferree, 1984). However, if root pruning is carried just prior to the period of active root growth, when soil moisture is adequate, new roots will be produced and water uptake will likely recover.

When the root to shoot ratio is reduced by root pruning, the plant reacts by restoring its internal equilibrium. During this process, more mineral nutrients and growth hormones are directed towards the root system to re-establish the root to shoot ratio in favour of the roots. Root pruning would be expected to result in an increase in root tips synthesizing cytokinins. Transport of cytokinins from the roots may stimulate above-ground growth. Plant species have characteristic root:shoot ratios and aerial growth is dependent to a large extent on below ground growth. This was demonstrated in a trial where the shoot growth rates of young grapevines were shown to be regulated by root volume (Buttrose & Mullins, 1968). Root pruning disrupts this ratio causing the plant to initiate a response to redistribute growth in support of root development, while shoot growth is reduced. Peach seedlings subjected to root restriction exhibited reduced growth rates and aerial growth, followed by rapid root growth and increased plant size (Richards & Rowe, 1977). Sultanina grapevines in Upington that were subjected to different intensities of root pruning *i.e*. one side of the row and both sides of the row, experienced reduced shoot growth during the first year following the treatment, particularly in the two-sided treatment (Van Zyl & Van Huyssteen, 1987). However, during the second year, shoot growth was more or less restored to similar levels. In the same trial, the yield of root pruned grapevines tended to increase in the same period. It follows that root pruning for improved above-ground performance should not be done regularly. This was further demonstrated by Saayman and Van Huyssteen (1983) where regular, severe root pruning reduced growth and yield of Colombar grapevines. Apart from the relationship between root growth and above-ground vegetative growth (Wheaton *et al*. 2008), grapevine vegetative growth is also related to soil nutritional status (Grant & Matthews, 1996), effective soil depth (Saayman & Van Huyssteen 1980; Saayman, 1982; Myburgh *et al*., 1996; McClymont *et al*., 2006), and is sensitive to water stress (Schultz & Matthews, 1988; Smart & Coombe, 1983). Excessive vegetative growth and the subsequent shading effect can bring about poor fruit initiation in buds (May & Antcliff, 1963), induction of early bunch stem necrosis (Perez & Kliewer, 1990), poor fruit set (Ebadi *et al*., 1996) and reduced berry quality (Dokoozlian & Kliewer, 1996). Inadequate vegetative growth can result in insufficient leaves, low yields, reduced sugar accumulation and berry sunburn.

The effect of root pruning or deep tillage on juice and wine quality has not been quantified in most of the root pruning studies. However, deep ripping and a permanent cover crop had no effect on juice total soluble solids (TSS) and TA of irrigated Colombar grapevines (Saayman & Van Huyssteen, 1983). Where root pruning is followed by an increase in vegetative growth, changes in berry quality are possible. Besides inherent characteristics, berry composition is determined by the interaction of various environmental factors and management practices. Environmental factors such as solar radiation (Kliewer, 1977; Dokoozlian & Kliewer, 1996), temperature (Buttrose *et al*., 1971; Southey, 2017), rainfall (Jones & Davis, 2000) have been linked to grape quality. Certain management practices can manipulate aspects of grapevine growth, in particular, canopy development, to control its exposure to climatic conditions. These include trellising, soil nutritional management, pruning, irrigation, summer canopy management (Iland, 1989a).

Excessive vegetative growth may result in shading which has various consequences for berry development and quality. The optimal leaf temperature range for photosynthesis is 18-33°C, which is the main factor controlling sugar accumulation in the berries (Iland, 1989). Metabolic reactions occurring in the berry, that govern acid, phenolic, anthocyanin and flavour compound levels, respond to berry temperature, which is influenced by canopy size and density. Leaf temperature responds to ambient temperature, SWC and wind, while berry temperature is also sensitive to the solar radiation and the position on the bunch (Iland, 1989). Berry pH is a function of the acid present in the berry, the ratio of malic to tartaric acid and the quantity of K^+. Several scenarios can arise in response to canopy shading and are illustrated by Iland (1989). Where the effect of leaf shading dominates the effect of berry shading, reduced efficiency of photosynthesis results in export of more K^+ to the berries. This increases the berry pH and decreases the TA and can have a negative effect on anthocyanin production. Where the effect of berry shading dominates the effect of leaf shading, lower berry temperature slows malice acid respiration resulting in a higher malic acid, lower pH and higher TA. Alternatively, an increased pH and increased TA can occur when the leaf shading effect dominates the pH equilibrium and the effect of berry shading dominates the TA level. Furthermore, shading can induce suboptimal berry temperatures for anthocyanin production. Apart from the effect of canopy on berry quality, high K^+ availability in the soil can increase K^+ uptake by grapevines resulting in high berry K^+. Where grapevine vegetative growth is poor, over-exposure of leaves and berries can occur, resulting in either higher juice pH and lower TA, or higher juice malic acid, TA and higher TA (Fig. 2.2).

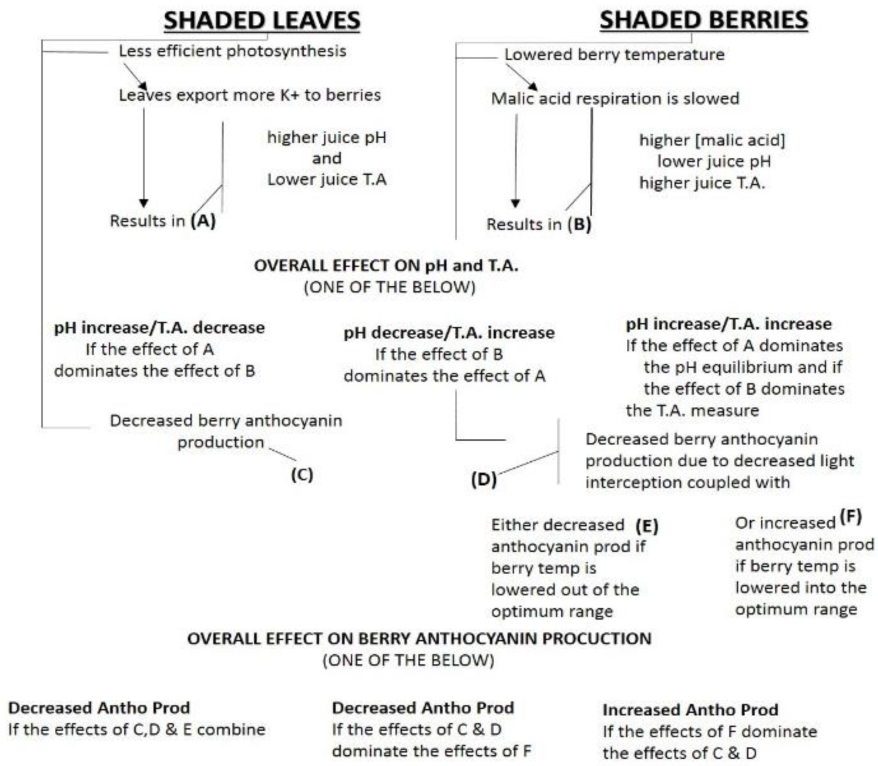

Figure 2.2. The effect of canopy density on grape and juice composition as illustrated by Iland (1989).

Juice and wine characteristics are determined by complex interactions between various chemical compounds and parameters but pH may be considered one of the most important factors affecting it. Taste perception, particularly sweetness and sourness, are related to pH, as well as wine flavour, colour and expression of fruit aromas. Furthermore, pH affects a wine's oxidative and microbiological stability (Boulton, 1980). Acidity, which governs the perception of bitterness and astringency due to tannins, is also dependent on wine pH. Grape berries contain of two groups of phenolic compounds namely, flavonoids and non-flavonoids. Proanthocyanidins (tannins), anthocyanins and flavan-3-ols are three major types of flavonoids (Conde *et al*., 2007). Tannins which are polymerised flavan-3-ols are responsible for astringency and are found in the skin, seeds and peduncle. Anthocyanins are extracted from the skin. The position of their equilibria, which is sensitive to pH and SO_2, is largely responsible for red wine colour (Somers & Evans, 1974). Wine colour is often the first parameter judged when evaluating wine quality and is therefore an important quality indicator. Inherent grape characteristics such as phenolic composition and concentration, as well as environmental factors, such as solar radiation (Kliewer, 1977), water constraints (Matthews & Anderson, 1988; Choné *et al*., 2001), soil N levels (Choné *et al*. 2001; Delgado *et al*., 2004) and disease pressure, affect phenolic development and wine quality, as do winemaking procedures. Grapevine water status has been shown to affect vegetative growth and fruit development, thereby influencing berry quality (Dry & Loveys, 1998). Ristic *et al*. (2007) showed that wines made from shaded fruit had lower colour, total phenolics, tannins and anthocyanins, and exhibited differences in sensory attributes.

2.3.2 Furrows in the work row

Creating furrows in the work row is a tillage practice seldom applied in recent years. In the past, it was traditionally carried out in alternate work rows using a furrow plough *(vlekploeg)* during the winter months. In some instances, pruned shoots, compost or fertilizer were deposited into the furrow and then worked in or closed up using an '*oprolploeg*' towards the end of winter (Van Huysteen, 1981).

Since furrows deeper than 30 cm were seldom achieved due to the considerable traction required, roots were only trimmed in the upper soil layers. Furthermore, the timing of application also meant that increased compaction occurred because of wetter soil conditions. Where shallow (vlak vlekvoor) and deep (diep vlekvoor) furrows of 15 to 20 cm and 20-30 cm, respectively, were compared to straw mulch, herbicide treatment, clean cultivation and weed control with a brush cutter, the furrow treatments did not have any beneficial effect on shoot growth, pruning mass and yield compared to clean cultivation (Van Huysteen, 1977). In fact, the yields tended to be lower under the shallow furrow treatment (Table 2.1). The furrow plough treatments in the aforementioned trial were applied in alternate rows. Both furrow plough treatments had no effect on juice TSS, TA and pH.

Table 2.1. The influence of different tillage practices on yield of Chenin blanc/101-14 Mgt. under dryland conditions at Nietvoorbij (Van Huysteen, 1977 in Burger & Deist, 1981).

Season	Grapevine yield at 20°B (t/ha)					
	Shallow furrows	Deep furrows	Straw mulch	Herbicide control	Clean cultivation	Brush cutter
1971/72	4.32	4.89	7.64	4.35	4.11	1.60
1972/73	4.83	5.07	8.07	3.73	4.74	1.23
1973/74	5.86	7.40	9.93	7.87	6.00	1.81
1975/75	7.50	9.18	9.53	9.81	7.72	1.47
1975/76	8.58	10.75	12.29	10.84	10.29	3.39
1976/77	7.85	9.19	13.63	10.94	9.38	3.40
1977/78	16.71	20.28	25.13	20.84	19.28	8.85
Total	55.65	66.76	86.22	68.38	61.52	21.75
Average	7.95	9.54	12.32	9.77	8.79	3.11

2.3.3 Organic matter incorporation

2.3.3.1 The properties of organic material used for soil amelioration

Organic matter can be defined as any material containing carbon (C) compounds formed by living organisms, and includes plant residues, animal manures, sludges, green manures and compost. The benefits of organic matter incorporation are well-recognized although in commercial agriculture it is a practice often considered expensive and results are likely to be seen over the long term. Most of these benefits relate to improving soil physical, chemical and biological properties by increasing the SOM content and thereby creating a favourable environment for enhanced root growth. Soil organic matter and pH are two commonly used indicators of soil quality (Magdoff & Weil, 2004). Organic carbon is an organic-matter-related property used to assess organic matter content of soils. Soil supports plant growth by providing nutrients and retaining water at adequate levels for plant uptake, by providing physical support for growth and adequate rooting depth, as well as a network of pores to facilitate gaseous exchange and root development and the support of soil organisms (Magdoff & Weil, 2004). Soil organic matter plays a major role in these functions, but conventional management practices tend to cause it to decrease.

In addition to improving the soil environment for better crop production, OM incorporation is considered to be one of the most important strategies to mitigate the greenhouse effect through carbon sequestration. Loss of C to the atmosphere from the soil organic carbon pool occurs through erosion, leaching and accelerated mineralization. Excessive tillage, removal of cover crops, desertification and erosion result in loss of OM. Mechanical tillage has been shown to reduce the organic matter content of soils, compared to no-tillage management (Franzluebbers, 2002; Fourie, 2007). Aeration of soil during mechanical cultivation speeds up OM decomposition, as do high temperatures and moisture levels. Agricultural management practices that increase accumulation of SOC facilitate C sequestration. Although the chemical composition of SOM fluctuates according to location, time of soil sampling, and at what stage of the decomposition process it is, it is comprised of approximately 50% C, 40% oxygen (O), 5% hydrogen (H), 4% Nitrogen (N) and 1% sulphur (S) and the OM content of agricultural soils range from 1% to 10% (Schjønning *et al.*, 2004).

The use of certain grass and cereal species for cover crops provides numerous advantages for soil management including increased SOM content and microbial activity (Steenwerth & Belina, 2008), improved soil structure, reduced compaction, increased porosity and infiltration (Linares *et al.*, 2014). On the other hand, cover crops can induce water deficits in dryland vineyards if not destroyed before bud break (Van Huyssteen & Weber, 1980b). Compost is the semi-stabilised product containing humus, resulting from the chemical and biological decomposition of organic material. It is a complex, heterogeneous mixture of organic substances such as plant material and animal manure that have undergone various degrees of decay and decomposition. Organic material consists of mainly carbohydrates, lignin, proteins and lipids which are decomposed to form humus. A large number of studies have demonstrated the benefits of increased SOM by compost additions (Morlat & Symoneaux, 2008; Brown & Cotton, 2011; Ponchia & Bozzolo, 2012).

The source of organic material, composition and the rate of application play a role in the effects of OM incorporation. Given the variable nature of compost and its constituents, analysis before application is necessary to rule out any risks of contamination by pesticides, herbicides, pathogens or toxicity due to heavy metals such as Zn^{2+}, Cu^{2+} and Pb^{2+} (Cass & McGrath, 2004). High electrical conductivity (EC) measured in compost can indicate high salinity, particularly where the compost comprises a large portion of manure. High levels of Na^{+} can result in sodicity, which has a negative effect on infiltration (Agassi *et al*., 1981).

2.3.4 Effect of OM on selected soil properties

2.3.4.1 Soil organic matter content

The value of compost lies in its potential to increase SOM and restore soil structure, and less so in its ability to serve as a nutrient source. In a long-term study comparing amendments of crushed pruned vine-wood, cattle manure and spent mushroom compost, all amendments increased total soil organic carbon, soil water-holding capacity and reduced bulk density, compared to the unamended control (Morlat & Chaussod, 2008). The quantity of compost required to increase SOM levels can be substantial and economically unviable. However, in the aforementioned study, an application of 2 t/ha crushed pruned vine-wood was most beneficial in increasing SOM content without any adverse effects on the environment and grapevines such as leaching and N over-supply. Where 5 t/ha compost was applied to two vineyards in Italy, soil OM, humification index, microbial biomass as well as yield per vine and grape quality increased (Ponchia & Bozzolo, 2012).

2.3.4.2 Aggregate stability and porosity

Soil structure is a key element in determining the favourability of the soil environment for root growth and is governed by aggregate stability. Many conventional vineyard management practices, such as excessive tillage or tillage during unsuitable soil moisture conditions, have a negative effect on aggregate stability and soil structure. Organic matter contributes to stabilization of aggregates through the binding effect of fungal hyphae and roots as well as through secretions by roots, microorganisms and macro-organisms (Cass & McGrath, 2005). Soil aggregation involves the rearrangement of particles, flocculation and cementation (Duiker *et al.*, 2003) and is facilitated by SOC, biota, ionic bridging, clay and carbonates (Bronick & Lal, 2005). Aggregates form *via* the interaction of mineral particles with organic and inorganic materials and can be grouped by size (Bronick & Lal, 2005). Different types of organic material vary in their effect on soil structure. The addition of "immature" compost to a silt loam soil resulted in a significant increase in aggregate stability due to enhanced microbial activity, whereas mature compost resulted in a less substantial but longer-lasting increase in aggregate stability due to enhanced aggregate cohesion (Annabi *et al*., 2007). In a study where different urban composts amendments and a farmyard manure amendment were compared, all amendments contributed to an increased organic carbon content and enhanced aggregate stability (Annabi *et al*., 2011). When soil structure is degraded, for example when aggregates are pulverised or smeared, the network of pores or channels is disrupted. Aggregate stability therefore influences the porosity of a soil and its ability to store water. Increased porosity due to tillage in many cases is short-lived as tillage tends to have a negative effect on soil structure in the long term (Franzluebbers, 2001).

There are various standards used to define the different size classes for the quantification of pore size distribution but in this review the criteria employed by Kay & VandenBygaart (2002) is used. They are as follows: macro-pores are those with diameters >30 µm; meso-pores are those with diameters 0.2-30 µm and micro-pores are with diameters <0.2 µm. Macro-pores are largely responsible for facilitating water infiltration, movement and drainage and therefore aeration too. Root growth and earthworm burrowing also occur in these larger pores. The meso-pores are primarily responsible for water storage, while water in the micro-pores is largely not plant available water (Kay & VandenBygaart, 2002). The ability of roots to exploit a soil profile is therefore largely dependent on water and soil structure which is indirectly dependent on SOM.

2.3.4.3 Infiltration/hydraulic conductivity

Water infiltration and movement in the soil requires pores at the soil surfaces, in particular macro-pores, which are created by plant roots as well as by OM addition. Organic matter has a stabilizing effect on pores, which keeps the channels intact, thereby facilitating hydraulic conductivity and drainage which are critical for soil water retention. (Cass & McGrath, 2004). Soil surface crusting is a form of soil structure degradation which inhibits infiltration, resulting in an increase in runoff and a reduction in water available to the plant.

2.3.4.4 Water-holding capacity

While compost has the ability to store water, the amount is less than that stored by the meso- and micro-pores which are maintained by stable aggregates. A field study carried out in California to quantify the effects of compost application on agricultural soils showed that sites that received compost application demonstrated significant increases in SOC, as well as increased microbial activity and gravimetric soil water (Brown & Cotton, 2011). Likewise, sandy soils treated with sewage-sludge compost exhibited reduced soil strength and increased soil water content (Tester, 1990).

2.3.4.5 Soil pH and nutrient availability

Apart from the benefits to soil physical properties, OM can increase or decrease soil pH, depending on the soil type, initial soil pH, addition rate and the chemical composition of the organic material (Rukshana *et al*., 2011). The possible mechanisms by which soil pH responds to organic compounds are illustrated in Figure 2.3. (Rukshana *et al*., 2011). Soil pH can increase due to dissociation of H^+.

Where an increase in soil pH occurs in response to compost addition, it is a result of decarboxylation of organic/bicarbonate anions in the organic material. The long-term addition of organic amendments to a sandy soil in the Loire Valley had no effect on soil pH, with the exception of a slight decrease towards the end of the study (Morlat & Chaussod, 2008). Urban solid waste compost application increased soil pH of a clay sandy soil, due to the high Ca^{2+} content (Hernando *et al*., 1989). Similarly, soil pH in a vegetable trial increased in the 0-15 cm soil layer in response to municipal solid waste compost applications of 50 and 100 t/ha (Giannakis *et al.,* 2014).

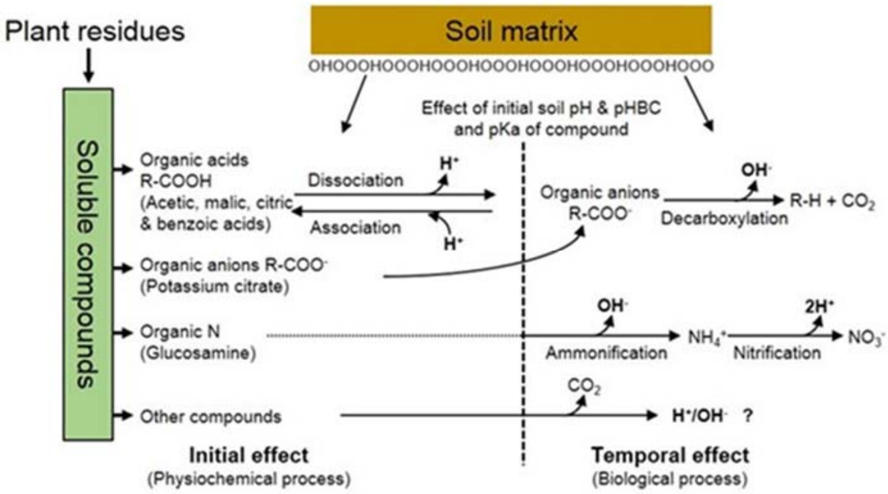

Figure 2.3. Diagram illustrating possible mechanisms of soil pH changes upon addition of model compounds (redrawn from Rukshana *et al*., 2011).

2.3.4.6 Biological activity

Organic matter supports microbes and soil fauna by providing a food and energy source, supplying the substrates for mineralisation and by creating a soil environment favourable to growth, in terms of structure, water and oxygen supply. Soil microbes are responsible for facilitating many biochemical processes that support plant growth and the release of nutrients that are in a plant-available form. Some plant beneficial microorganisms found especially in the rhizosphere include N-fixing bacteria, rhizobacteria, saprophytic microorganisms and mycorrhizal fungi, the microbial populations of which are susceptible to changes to in the soil environment surrounding the grapevine roots. Arbuscular mycorrhizal fungi increase the root surface area for nutrient uptake by forming symbiotic relations with roots (Magdoff & Weil, 2004). Microbial communities mediate important processes that drive C and N cycling within ecosystems. Several studies have demonstrated the positive effects of organic matter on microbial diversity (Zhong *et al*., 2010) and the positive effect of compost application on microbial activity (Mäder *et al*., 2002; Ros *et al*., 2006; Brown & Cotton, 2011; Ponchia & Bozzolo, 2012).

2.3.5 Effect of organic matter incorporation on growth and yield

The effects of organic matter amendments can take some time to reflect in plant performance. In a 28-year field study, various organic amendments only had a significant effect on the performance of Cabernet franc grapevines after 14 years (Morlat, 2008). Furthermore, high rates (20 t/ha/yr) of organic manure amendments supressed the grapevine root system and decreased vegetative growth and yield, most likely due to an excess of N in the soil. Moderate rates of crushed pruned vine-wood stimulated root growth and tended to increase pruning mass and yield, whereas moderate rates of manure had no suppressive effect on the root system. Similarly, where different compost amendments were compared in a 6-year old Cabernet Sauvignon vineyard, compost from crushed-pruned vine wood had a more positive effect on grapevine root growth than manure compost, particularly where it was added on the grapevine row rather than the work row (Gaiotti *et al*., 2016). However, both the manure compost and the crushed pruned vine-wood compost increased vegetative growth and yield over a 5-year period. In contrast, 40 t/ha compost and 28 t/ha straw applied during soil preparation to a Hutton/Clovelly soil had no effect on performance of Colombar/143B Mgt (Saayman & Van Huyssteen, 1980). These results were supported by Saayman (1982) in a related trial where compost and straw amendments had no effect on grapevine performance.

2.4 Summary

Where access to water is limited, particularly in dryland vineyards, mulching is considered to be an effective water-saving practice. However, the water saving related results are variable and differ among soil types and with different mulch materials and application rates. The ability of straw mulch to reduce evaporation also seems to be in question, with a number of studies describing reduced evaporation rates only during the initial stage. This implies that under conditions of limited rainfall, mulches may not provide substantial water-saving benefits. Nevertheless, there are reported benefits of mulch on grapevine growth and yield, but information on the ideal mulch rates is limited.

In a previous study, the furrow plough provided no additional benefits to grapevine growth, where grapevine prunings were incorporated into the furrows. Incorporation of organic material by means of a furrow plough is not common practice in recent years, but may provide an effective alternative to root pruning with compost where deep tillage is not required or suitable.

In vineyards where mulch application is impractical, compost incorporation has numerous benefits for soil physical conditions and grapevine growth. In dryland vineyards, where the amount of precipitation entering the soil needs to be maximised, maintenance of soil structure is critical. While root pruning is an effective method to alleviate compaction, the effects on grapevine performance are not well understood, with few studies having evaluated the effect of root pruning on yield and quality.

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Chapter 3

Research results

The effect of compost mulch thickness on soil water conservation and grapevine performance

CHAPTER III: THE EFFECT OF COMPOST MULCH THICKNESS ON SOIL WATER CONSERVATION AND GRAPEVINE PERFORMANCE

3.1 Introduction

Although there is some literature available on mulching with various materials and its effect on soil compaction and erosion, nutrient release, weed control, soil microbial diversity grapevine yield and quality (Van Huyssteen & Weber, 1980a & b; Agnew *et al*., 2002; Forge *et al*., 2003; Chan *et al*., 2010; Nguyen *et al*., 2013), little is known about the use of compost as a mulch and its effect on grapevine performance under dryland conditions.

Mulches may consist of organic or inorganic materials, which are placed on the soil surface as a protective layer. In the past, black plastic mulches were commonly used in many crops to minimize evaporation and control weed growth (Van der Westhuizen, 1980), and more recently reflective materials and breathable geotextiles. Although straw mulch has been shown to be effective in retaining soil moisture (Van Huyssteen & Weber, 1980c; Agnew *et al*., 2002; DeVetter *et al*., 2015), their efficacy may not endure long enough to warrant the cost of application. Myburgh (2013) found that the water conservation effect of selected wheat straw mulch treatments lasted for only two seasons. Given the movement towards the use of more biodegradable materials and the implementation of environmentally sound practices, organic mulches have in recent years become more appealing to growers. Some benefits of organic mulches include improved water retention and infiltration (Pinamonti, 1998; Mulumba & Lal, 2008; DeVetter *et al.*, 2015), reduced soil temperature fluctuation (Pinamonti, 1998; Chan *et al*., 2010; Fourie & Freitag, 2010; De Vetter *et al.,* 2015) and weed control (DeVetter *et al*., 2015). Mulching can also improve aggregate stability (Mulumba & Lal, 2008; Jordán *et al.,* 2010; DeVetter *et al.,* 2015), increase soil organic carbon (Saroa & Lal, 2003), reduce erosion (Mannering & Meyer, 1963), and increase grapevine yield (Van Huyssteen & Weber, 1980b; Buckerfield & Webster, 1999; Nguyen *et al*., 2013). Mulch is also capable of conserving soil water by reducing evaporation (Van Huyssteen *et al*., 1984). Variable composition, ease of application, economic viability and rapid weathering are some of the challenges posed by organic mulch application.

Soil water content is one of the most critical factors affecting grapevine growth (Lategan, 2011). According to Van Zyl and Van Huyssteen (1984), the average annual water requirement of a grapevine can vary from 300 mm to 600 mm, which in many arid and semi-arid regions is partially or mostly fulfilled by irrigation. However, South Africa has *c*. 12800 ha of dryland vineyards (C. Whitehead, Sawis, personal communication) which therefore rely only on the annual rainfall to fulfil their water requirements. The annual rainfall LTM for South Africa is 608 mm (De Jager, 2016). In the Western Cape, the average annual rainfall for the different agro-climatic zones varies from 166 mm to over 510 mm (Jack & Johnston, 2016). The shift in weather patterns, especially temperature (Bonnardot *et al.,* 2011) and rainfall (DEA, 2013) has necessitated the implementation of adaptive management practices that are effective in conserving soil moisture through reduced evaporation and runoff, and increased soil water holding capacity. Grapevines take up water and nutrients through their roots *via* the soil-plant-atmosphere continuum. Their fine roots play an important role in plant functioning but due to their location are exposed to greater temperature and moisture fluctuations. Under normal night time conditions, the grapevine is capable of internal hydraulic redistribution for maintenance of fine roots (Bauerle *et al*., 1998). However, when the soil is extremely dry and atmospheric conditions are such that there is no reduction in transpiration, fine roots may be susceptible to desiccation. This may jeopardize membrane integrity, leading to increased electrolyte leakage as well as root death. Since mulching has been shown to reduce soil temperature fluctuations and improve soil water retention, it should help maintain a more favourable environment for fine root development. Very little, however, is known about the complex response of grapevine root systems and the various root types to different soil and atmospheric conditions and how to manipulate root lifespan and health for improved grapevine performance.

Grapevine plant water status is strongly linked to soil water content (Williams & Araujo, 2002; Laker, 2004; Lategan, 2011), as well as to atmospheric conditions (Laker, 2004). Stem water potential (Ψ_S) is considered a reliable indicator of grapevine plant water status (Williams & Araujo, 2002 and references therein). The Ψ_S seems to correlate with transpiration in non-irrigated grapevines (Choné *et al*., 2001). Furthermore, it was shown that Ψ_S is better related soil water content than leaf water potential (Ψ_L) (Bruwer, 2010). One of the grapevine's mechanisms of adaption to water stress is reduced growth, which is stimulated by hormone release in specific plant organs. Mild water constraints before véraison are required to reduce vegetative growth during ripening, whereas severe water constraints at phenological stages such as flowering and reproduction, can be particularly detrimental to plant functioning and berry development (Lategan, 2011). Growers with dryland vineyards in arid climates must avoid soil moisture depletion to such an extent that severe water stress is induced at these critical stages and to buffer the grapevines against harsh atmospheric conditions. Previous research showed that high to severe water constraints in Merlot tended to reduce berry mass and improved wine quality (Myburgh, 2011). Laker (2004) noted that higher water stress in Sauvignon blanc during a drier season may have been responsible for a decrease in overall wine quality.

Taking all of the above-mentioned benefits of using composts into consideration, the aim of the study was to investigate the effect of compost as a mulch on soil-plant water relations and grapevine performance. As the knowledge of the use of compost as a mulch under dryland conditions is so limited, the study was carried out under dryland conditions using compost, to determine the effect of compost mulch rate on soil moisture retention or loss.

3.2 Materials and Methods

3.2.1 Vineyard characteristics

The field trial was carried out in a fourteen-year old experimental Shiraz/101-14 Mgt vineyard (Fig. 3.1) on the Welgevallen experiment farm in Stellenbosch in the Coastal grape growing region of the Western Cape. The region has a Mediterranean climate, and based on the growing degree days (GDD) from September until March (Winkler *et al*., 1974), the specific locality is in a class IV climatic region (Le Roux, 1974). The vineyard was situated 120 m above sea level (a.s.l.) on a flat terrain. Grapevines were planted 2.7 x 1.5 m and trained onto a vertical shoot position (VSP) system with a single cordon and 5 spurs per arm (Booysen *et al.*, 1992). The grapevine rows were orientated in a *NNW-SSE* row direction. The vineyard was previously irrigated by means of drippers but for the purposes of the field trial, it was converted to dryland. Characteristics of the vineyard are given in Table 3.1.

Table 3.1. Characteristics of the vineyard where the mulch trial was carried out in Stellenbosch.

Descriptor	Vineyard Details
Climate	Mediterranean
Locality	Welgevallen experiment farm
Lat/Long	33.9402° S, 18.8657° E
Elevation	157 m a.s.l.
Slope	Flat
Scion	Shiraz (clone SH9C)
Rootstock	101-14 Mgt (*Vitis riparia* x *Vitis rupestris*)
Grapevine spacing	2.7 x 1.5 m
Trellis/training system	Movable Five Strand Lengthened Perold
Pruning system	Two bud spurs
Irrigation	Dryland

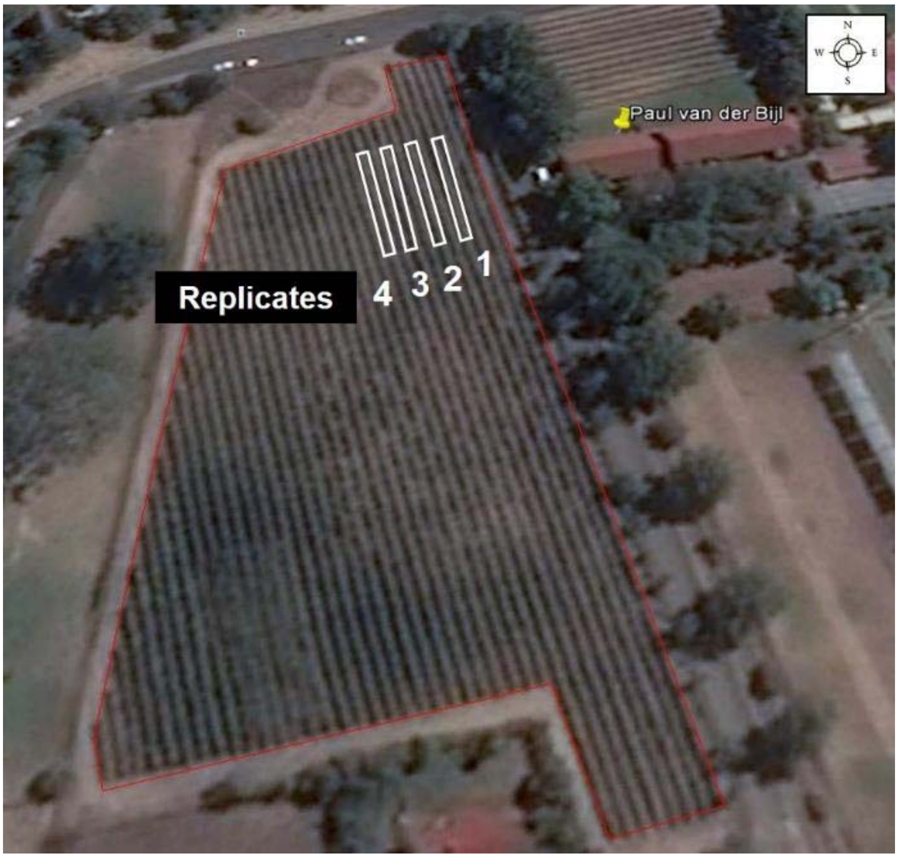

Figure 3.1. An aerial image showing the location of the four replications where the different mulching treatments were applied.

3.2.2 Atmospheric conditions

The region's climate was described using long term air temperature, relative humidity (RH), reference evapotranspiration (ET_O), rainfall, wind speed and incoming solar radiation (insolation) data collected from an automatic weather station of the Agricultural Research Council (ARC) Institute for Soil, Water and Climate (33.9591˚ S,18.8337˚ E, 125 m mean height above sea level) at Fleurbaix, Stellenbosch. The data were obtained from the ARC Institute for Soil Climate and Water in Pretoria. The long term data were used to compare the atmospheric conditions during the 2015/16 season and 2016/17 season to the long term mean (LTM) and to classify the climate of the area on a macro climatic scale. The mean data from the weather station were used to calculate the Winkler Index for the experiment site. Since the Fleurbaix station was transitioning from a mechanical to an automatic station, data were not available from April to August 2015. Rainfall data for this period were estimated by correlating rainfall data from a pluviometer on the Nietvoorbij (NVB) experimental farm (33.9158° S, 18.8616° E, 154 m a.s.l) of the ARC Infruitec-Nietvoorbij with that of the weather station at Fleurbaix between September 2015 and April 2017 and using the following equation:

$$FB_{rainfall} = 1.254{*}NVB_{rainfall} + 4.665 \qquad (R^2 = 0.924;\ n = 16;\ s.e. = 13.5;\ p < 0.001) \qquad \text{(Eq. 3.1)}$$

where $FB_{rainfall}$ is the total monthly rainfall measured at the Fleurbaix weather station and $NVB_{rainfall}$ is the total monthly rainfall recorded at the Nietvoorbij experimental farm.

3.2.3 Experiment layout and treatments

3.2.3.1 Experiment layout

Compost mulch layers of 2 cm (T2), 4 cm (T3), 8 cm (T4) and 16 cm applied on the grapevine row were compared to the control treatment without any mulch (T1). All treatments were replicated four times in randomised block design (Fig. 3.2). Each plot consisted of four experiment grapevines with a buffer grapevine at each end and a buffer row on each side (Fig. 3.3).

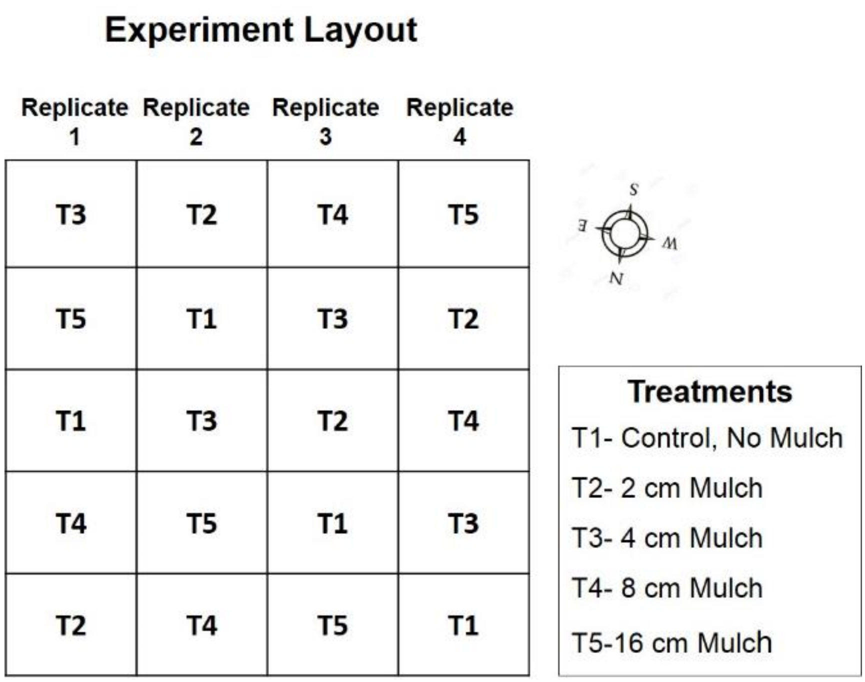

Figure 3.2. Mulch trial experiment layout.

Experiment plot layout

X	X	X
X	O	x
X	O	X
X	O	X
X	O	X
X	X	X

X	**Buffer grapevine**
O	Measurement grapevine

Figure 3.3. Mulch trial experiment plot layout.

3.2.3.2 Mulch composition

The compost was produced by a static windrow method and matured for six months before being applied to the vineyard. The compost comprised of grape marc, wheat straw, sheep manure, horse manure, cow manure, tomato plants and root shavings, and citrus waste. A compost sample was analysed a commercial laboratory (Elsenburg Agricultural Laboratory) and analysed for pH, resistance, moisture, density, N, P, K^+, Ca^{2+}, Mg^{2+}, Na^+, Mn^{2+}, Fe^{2+}, Cu^{2+}, Zn^{2+}, B^{3+}, C, NH_4^+-N and NO_3-N, before being applied to the vineyard. Except for the Fe^{2+} and ash content which were high, the composition was considered comparable to informal industry standards (Table 3.2). However, no explanation could be found for the high Fe^{2+} and ash content.

Table 3.2. The chemical characteristics of the compost prior to application in September 2015.

Compost variable	Value
pH	6.8
Resistance (ohm)	90
Moisture (%)	33.5
Density (kg/m^3)	796.7
N (%)	0.92
P (%)	0.38
K^+ (%)	0.42
Ca^{2+} (%)	2.9
Mg^{2+} (%)	0.2
Na^+ (mg/kg)	844.08
Mn^{2+} (mg/kg)	279.58
Fe^{2+} (mg/kg)	13848.9
Cu^{2+} (mg/kg)	20.59
Zn^{2+} (mg/kg)	134.67
B^{3+} (mg/kg)	12.18
C (%)	12.44
Ash (%)	74.9
NH_4-N (mg/kg)	1.69
NO_3-N (mg/kg)	20.23

3.2.3.3 Mulch application and mulch rates

The compost mulch was weighed in a container of known volume and then applied in September 2015 by hand, at the desired rates (2 cm, 4 cm, 8 cm & 16 cm depth/thickness) (Fig.3.4). The dry mass was determined by weighing a known volume of compost before drying it in an oven at 60°C, until constant mass was attained (Table 3.3). Twenty-two months after the mulches were applied, the height of the mulch remaining on the grapevine row was quantified and the degree of weathering evaluated.

Table 3.3 Treatments and their corresponding mulch application rate.

Treatment	Mulch thickness	Dry mass (t/ha)
1	0 cm	0
2	2 cm	29.5
3	4 cm	59.0
4	8 cm	118.0
5	16 cm	236.1

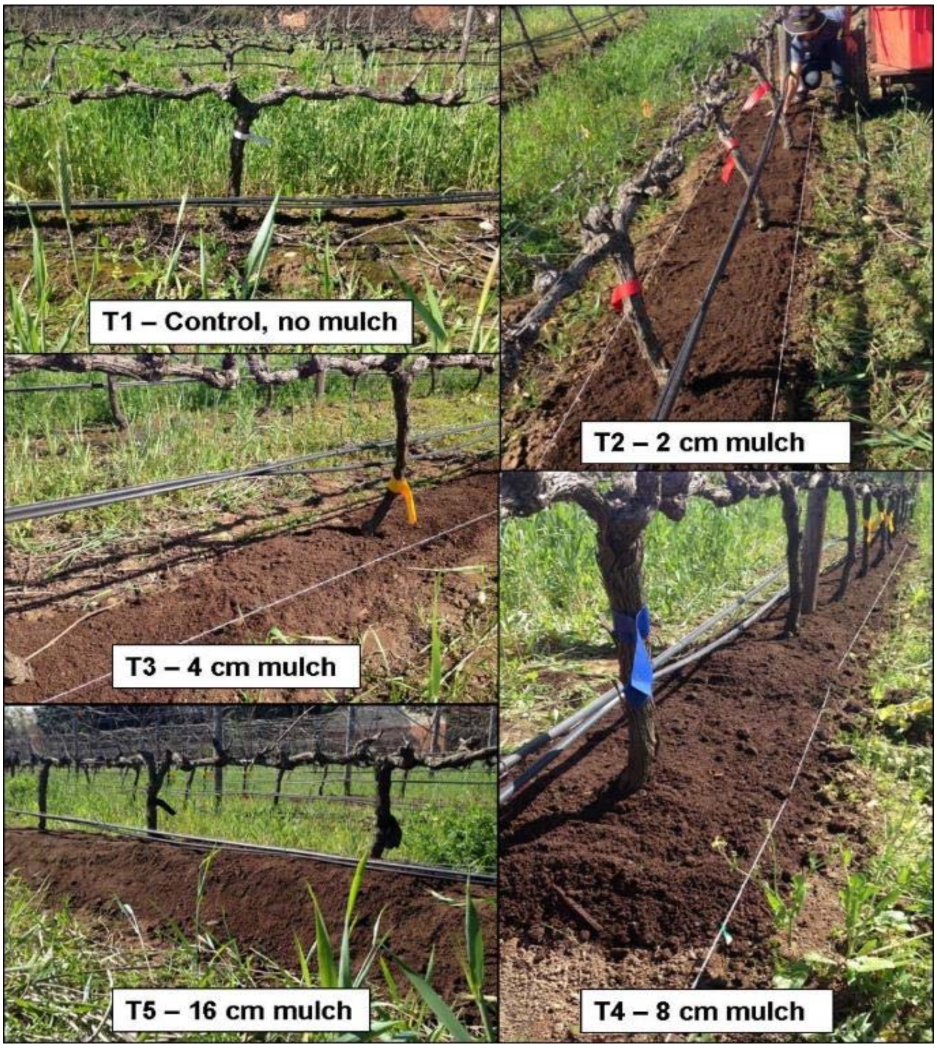

Figure 3.4. Mulch treatments applied to the grapevine row in September 2015.

3.2.4 Measurements

3.2.4.1 Soil water status

Soil water content (SWC) was measured with a neutron probe (HYDROPROBE 503DR, CPN®, California), using the neutron scattering technique. A 50 mm Ø class 4 Polyvinyl chloride [IUPAC: Poly(chloroethanediyl)] neutron probe access tube was installed on the vine row of each experiment plot using a 50 mm custom built auger. Soil water content was measured at 300 mm, 600 mm, 900 mm and 1200 mm soil depths. Measurements were carried out every fourteen days from September until harvest and once per month following grape harvest. Five standard count readings were taken while the probe was standing on the neutron probe case, before and after the actual readings were recorded. Neutron probe count ratios were obtained by determining the ratio between the actual readings at each depth and the average of the ten standard count readings. The neutron probe count ratios were calibrated against the volumetric soil water content (Θ_v). The gravimetric soil water content (Θ_m) was determined by collecting soil samples over the 0-300 mm, 300-600 mm, 600-900 mm and 900-200 mm depth increments using a Viehmeyer auger on the same days that neutron probe readings were taken. Soil samples were placed in metal cans of known mass and closed immediately. The samples were weighed on an electronic balance at the Irrigation laboratory at ARC Infruitec-Nietvoorbij. Thereafter, the cans were opened and placed in an extractor oven to dry at 105ºC for 24 hours (Hillel, 1980). After the samples were removed from the oven, the cans were closed and placed in a desiccator containing $CuSO_4$ crystals to cool down. Following this, samples were weighed and gravimetric soil water content was calculated by means of the following equation:

$$\Theta_m = (M_w - M_d) \div (M_d - M_c) \qquad \text{(Eq. 3.2)}$$

where M_w is the mass of the moist soil, M_d is the oven-dry mass of the soil and M_c is the metal can mass. Volumetric soil content was calculated as follows:

$$\Theta_v = \Theta_m \times \rho_b \qquad \text{(Eq. 3.3)}$$

Where ρ_b is soil bulk density. The ρ_b used was 1 500 kg/m^3 (P. Myburgh personal communication). Soil water content (SWC) for each layer was calculated as follows:

$$SWC = \Theta_v \times d \times 100 \qquad \text{(Eq. 3.4)}$$

where d is the depth of the soil layer (dm). The SWC content for the layers were summed to obtain the water content in the soil profile.

3.2.4.2 Water infiltration rate

Mini disk infiltrometers (Decagon Devices, Pullman, WA) were used to measure the water infiltration rate (I) into the soil (Fig. 3.5). Infiltration measurements were replicated three times in each plot. To prevent the infiltrometers from toppling over, they were clamped to 10 mm diameter steel rods driven into the soil. Measurements were carried out at a suction head of 0.5 cm to reduce preferential water flow in coarse pores made by insects or worms (Clothier & White, 1981). The rate of infiltration (mm/h) was calculated by means of the following equation:

$$K = \{[(V_i - V_e) \div 1000] \div 0.001521\} \times 60 \div \Delta t \qquad \text{(Eq. 3.5)}$$

where V_i is initial volume reading (mL) at the beginning of the measurement, V_e is volume reading (mL) at the end of the measurement, 0.001521 is the area of the ceramic plate at the bottom of the infiltrometer (m^2) and Δt is the time between consecutive measurements (min).

Figure 3.5. Mini disc infiltrometers being used to measure near-saturation hydraulic conductivity on the under vine bank.

3.2.4.3 Soil temperature

Eighty DS18B20 sensors were used in a "1-Wire" normal power configuration to measure the underground temperatures. The DS18B20 was chosen because of its robust and reliable nature as they can operate with up to 12-bit precision and can handle temperatures from -55C to 125C (±0.5) while being packaged in a waterproof industrial casing. Each sensor has a unique address assigned to it which enables it to be queried for its data. As the data is given in a digital form and not as a voltage level, there is also very little risk for data degradation or loss due to long wires. After the data has been collected to the central logger, the data is sent to an online data storage service where it can be accessed from any computer and downloaded. The sensors were calibrated in water with a thermometer to ensure accurate and comparable readings. Four sensors were placed in each treatment plot at different depths. The depths were 5 cm, 10 cm, 20 cm and 40 cm below the soil surface. In order to install the probe accurately at the desired depth, a peg was carefully inserted into the soil with a sensor attached. At the correct depth, the sensor was released from the peg and a soil slurry poured into the narrow gap surrounding the sensor and cable. The sensors were set to log data at half hour intervals.

3.2.4.4 Grapevine water status

Grapevine water status was quantified by measuring the midday stem (Ψ_S) water potentials in mature leaves on primary shoots using the pressure chamber technique (Scholander *et al*. 1965) and according to the protocol described by Myburgh (2010). Leaves were placed in bags at least one hour prior to measurement. The Ψ_S was measured in one leaf per treatment plot in three replicates on at least four occasions during the growing season. The measurement dates coincided with major phenological stages. A sharp blade was used to severe the leaf at the base of the petiole before placing the leaf and bag in the pressure chamber within a few seconds. Grapevine water stress was classified according to the thresholds (Table. 3.4) described by Lategan (2011).

Table 3.4. Water stress thresholds for predawn (Ψ_{PD}), leaf (Ψ_L), stem (Ψ_S) and total diurnal (Ψ_{Tot}) water potential in Shiraz/110R near Robertson as estimated by Lategan (2011) from the predawn leaf water potential (Ψ_{PD}) water stress classifications as proposed by Ojeda *et al.* (2002) and Van Leeuwen *et al.* (2009).

Class	Water stress	Water potential thresholds			
		(MPa)	(MPa)	(MPa)	(MPa)
I	None	$\Psi_{PD} \geq -0.4$	$\Psi_L \geq -1.8$	$\Psi_S \geq -1.3$	$\Psi_{Tot} \leq 14.2$
II	Weak	$-0.4 > \Psi_{PD} \geq -0.6$	$-1.8 > \Psi_L \geq -2.0$	$-1.3 > \Psi_S \geq -1.7$	$14.2 < \Psi_{Tot} \leq 19.1$
III	Medium	$-0.6 > \Psi_{PD} \geq -0.8$	$-2.0 > \Psi_L \geq -2.1$	$-1.7 > \Psi_S \geq -1.9$	$19.1 < \Psi_{Tot} \leq 23.3$
IV	Strong	$-0.8 > \Psi_{PD} \geq -1.0$	$-2.1 > \Psi_L \geq -2.2$	$-1.9 > \Psi_S \geq -2.0$	$23.3 < \Psi_{Tot} \leq 26.7$
V	Severe	$\Psi_{PD} < -1.0$	$\Psi_L < -2.2$	$\Psi_S < -2.0$	$\Psi_{Tot} > 26.7$

3.2.4.5 Vegetative growth

Grapevines in the experimental plots were pruned during dormancy July to two-bud spurs and the pruning mass per grapevine determined in the field using a hanging balance. The pruning weights were recorded for the 2014/2015, 2015/2016 and 2016/2017 seasons to determine grapevine vigour. Pruning mass per plot was converted to tonnes per hectare. The number of canes were counted and weighed.

3.2.4.6 Berry sampling and juice analysis

Berry development was monitored several times from véraison until harvest. One 50-berry sample was collected from the 10 grapevines per experiment plot. Berries were selected randomly from bunches on either side of the canopy. On each bunch, one berry was selected from the bottom, two from the middle and two from the top of the bunch. Analysis of the berries was carried out on the day of sampling. Berry fresh mass (g) and volume (mℓ) were measured by weighing and water displacement respectively. The 50-berry sample was crushed using a household handheld liquidizer by three consecutive pulses. The crushed berry slurry was poured through a small kitchen sieve. The skins and pulp were lightly pressed to allow all juice to pass through the sieve. Total soluble solid concentration (TSS) was measured using a digital pocket refractometer (Pocket PAL-1, Atago U.S.A. inc., Bellevue, WA, U.S.A.). Titratable acidity (TA) and pH were measured using an automatic titration device (Metrohm 785 DMP Titrino, Metrohm AG, Herisau, Switzerland).

3.2.4.7 Yield

Each experiment grapevine was harvested separately by hand in the 2015/16 and 2016/17 seasons. The harvested grapes were weighed in the vineyard using a portable balance (Mettler Toledo, Viper SW, 5 g–35 kg). The total number of bunches per grapevine was also counted and the yield per experiment plot determined in 2016 and 2017.

3.2.4.8 Micro-vinification

During the first season, grapes were pooled per treatment and two wines were made from each treatment. The grapes were micro-vinified at the experimental cellar of the Department of Viticulture and Oenology, Stellenbosch University. The grapes were crushed and destemmed into 50 L plastic drums and juice samples collected for ˚B, Titratable acidity and pH. Thirty mg/L SO_2 was added to the crushed grapes. The crushed grapes were inoculated with 30 g/hL of a commercial

Saccharomyces cerevisiae yeast (ICV-D21, Lallemand). Thirty g/hL Go Ferm Protect (Lallemand) was added to the rehydration water. Twenty-four hours after inoculation, co-inoculation with 0.01 g/ℓ Oenococcus Oeni (Enoferm Alpha, Lallemand) was performed to ensure malolactic fermentation. Fermentation was conducted on the skins at 25°C and the cap was punched down three times a day. After the sugar had dropped by 5°B (to approximately 20°B), a nutrient source was added in the form of Fermaid K (Lallemand). The must was fermented down to between 0°B and 5°B and the skins pressed at -1°B and at 1 Bar. Malolactic fermentation was completed at 20°C. After the Central Analytical Facility, Stellenbosch University, South Africa confirmed that malolactic fermentation was completed by determining malic & lactic acids enzymatically), the wines were racked off the lees and 50 mg/L SO_2 was added. Cold stabilization of the wines took place over 3 weeks at -4°C before adjusting the free SO_2 to 40 mg/L and botting under screw cap. The bottled wines were stored at 14°C until they were evaluated in August.

3.2.4.9 Sensory analysis

The wines were evaluated three months after bottling to ensure bottle shock did not interfere with sensory attributes. A preliminary tasting with a panel of experts was carried out to assess the wines for major differences in aroma and flavour between the treatments. The panel consisted of four experts in the field of sensory evaluation and viticulture. A decision on whether or not to perform sensory analysis on the wines was based on the results of this preliminary wine sensorial assessment.

3.2.4.10 Statistical analysis

The data were subjected to an analysis of variance. Least significant difference (LSD) values were calculated to facilitate comparison between treatment means. Means which differed at $p \leq 0.05$ were considered to be significantly different. Statgraphics® was used to fit linear regression models.

3.3 Results

3.3.1 Atmospheric conditions

3.3.1.1 Maximum and minimum temperature

In general, there were greater temperature fluctuations during the 2015/16 season compared to the 2016/17 season. The maximum monthly temperature showed similar trends during the two seasons and was comparable to the LTM except for January 2016, where the monthly mean maximum was 33.3˚C (Fig. 3.6). The 2015/16 monthly minimum temperature differed slightly from the LTM as well as the 2016/17 season in September, October and January. The mean monthly temperatures were also unexpectedly higher than the LTM and 2016/17 season for January. Although slightly lower temperatures were recorded during December, January and February, the maximum monthly temperature throughout the 2016/17 growing season was comparable to the LTM. The minimum monthly temperatures were also very similar to the LTM.

3.3.1.2 Relative humidity

The maximum relative humidity was higher than the LTM during October 2015 but lower than the LTM for the rest of the 2015/16 growing season (Fig. 3.7). With the exception of January 2016, relative humidity during the 2016/17 growing season was lower than the 2015/16 season and the LTM. The peak in Tx during January 2016 (Fig. 3.6) coincided with a reduction in maximum relative humidity (Fig. 3.7). The minimum relative humidity was also higher than the LTM during October

2015, and appeared to fluctuate below the LTM for the remainder of the growing season, except for December and February when it was quite similar to the LTM (Fig. 3.7). Lower monthly maximum relative humidity values than the LTM were recorded after September. The minimum relative humidity also tended to be lower than the LTM from October 2016, and deviated from the LTM to a lesser degree than the during the 2015/16 growing season.

3.3.1.3 Rainfall

Rainfall during the winter (April to Sept) of 2015 was considerably lower (*c*. 200 mm) than the LTM as well as the 2016 rainfall (Fig. 3.8 & Table. 3.5). The months of August to October 2015 were particularly drier compared to the same period in 2016 and to the LTM for those months. Rainfall during November 2015 and February 2016 was comparable to the LTM, whereas the rainfall during December 2015 and March 2016 was higher than the LTM (Fig. 3.8). The rainfall recorded for the winter of 2016 was comparable to the LTM.

3.3.1.4 Solar radiation, wind and evapotranspiration

Solar radiation during both the 2015/16 and 2016/17 growing season was higher than the LTM and followed a similar trend until March (Fig. 3.9). From March 2016, the solar radiation decreased to below the LTM whereas from February 2017 the solar radiation was higher than the LTM. Evapotranspiration during the 2015/16 season followed a similar trend to the mean monthly temperatures of that season (Fig. 3.9). The evapotranspiration was higher than the LTM and peaked in January when temperatures were highest, after which it decreased to below the LTM during February and March. This trend is in accordance with the solar radiation, which also declined to below the LTM during February. The wind speed recorded during the 2015/16 season was higher than the 2016/17 season and the LTM, except for December when wind speed for both seasons was comparable (Fig. 3.10). Wind speed during the 2016/17 season was higher than the LTM, with the exception of October when the recorded wind speed was lower than the LTM.

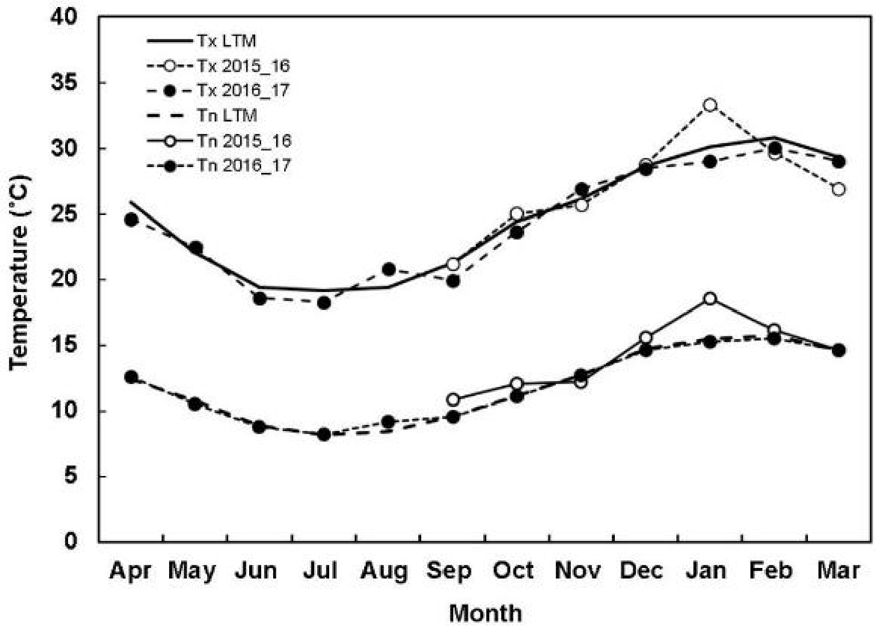

Figure 3.6. Maximum monthly mean daily maximum (Tx) and minimum (Tn) temperatures during the 2015/16 and 2016/17 seasons compared to the long term mean (LTM) in Stellenbosch

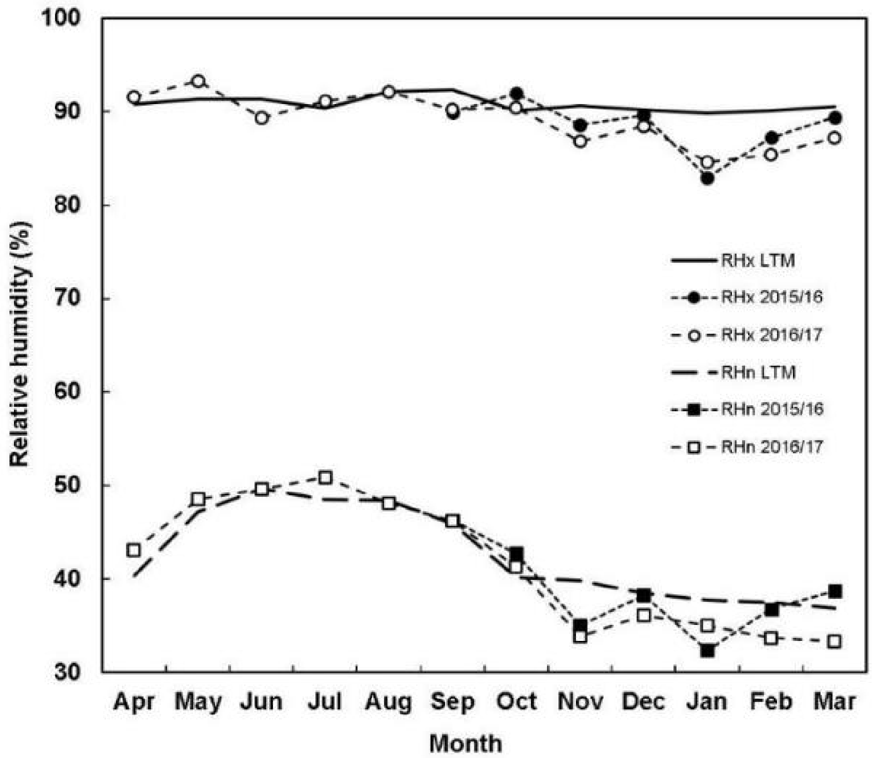

Figure 3.7. Maximum monthly mean daily maximum (RHx) and minimum (RHn) relative humidity during the 2015/16 and 2016/17 seasons compared to the long term mean (LTM) in Stellenbosch.

Table 3.5. Rainfall (mm) during the 2015/16 and 2016/17 season, compared to the LTM at the Fleurbaix weather station.

Month	Rain (mm)		
	LTM	2015/16	2016/17
April	*56*	4	78
May	*92*	36	32
June	*121*	114	136
July	*109*	107	170
August	*99*	44	102
September	*67*	26	61
October	*41*	4	32
November	*34*	30	4
December	*16*	47	9
January	*16*	10	47
February	*14*	13	0
March	*19*	39	11
Winter	*543*	331	580
Summer	*140*	143	102
Total	*683*	474	682

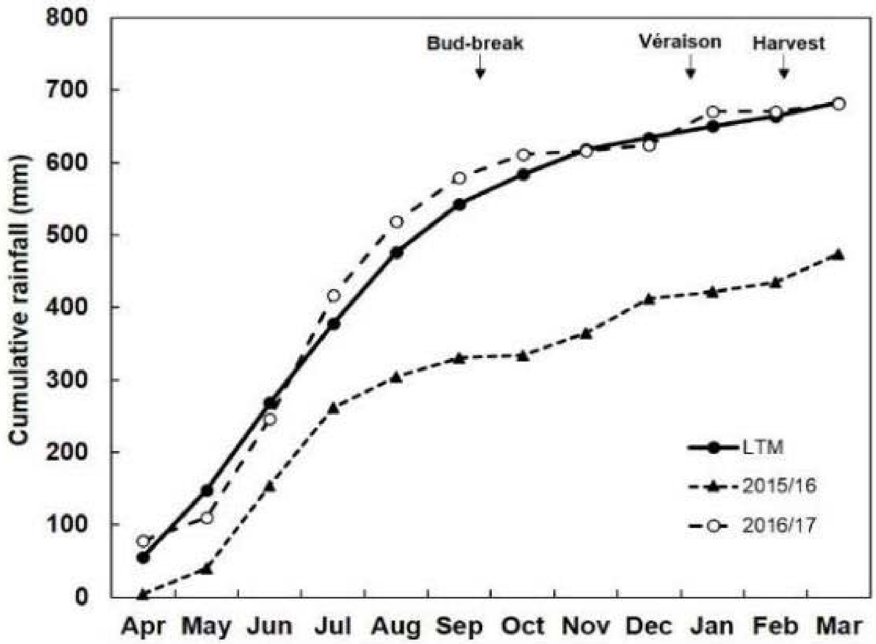

Figure 3.8. Cumulative rainfall during the 2015/16 and 2016/17 seasons compared to the long term mean (LTM) in Stellenbosch.

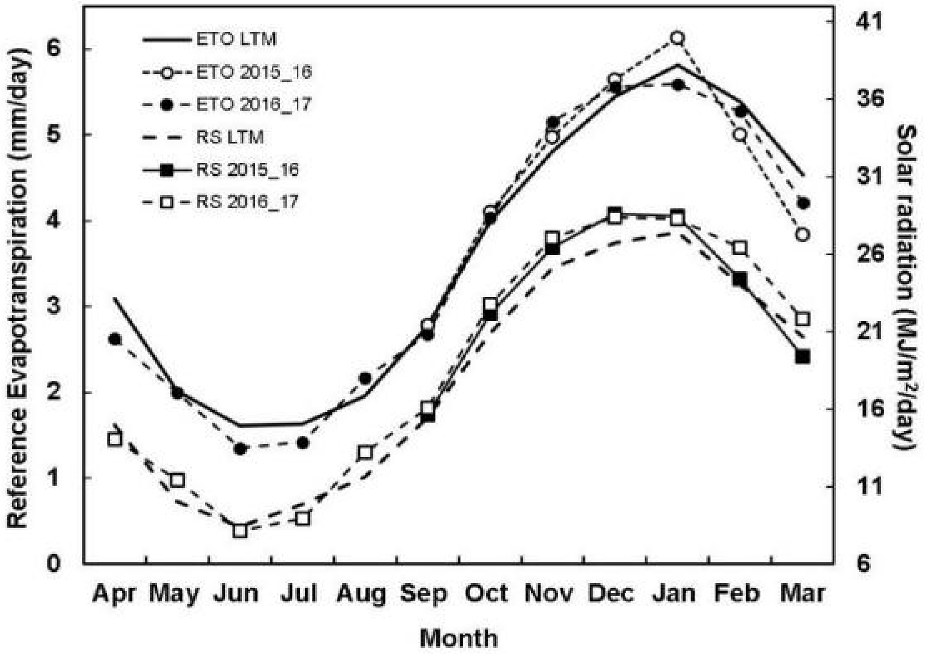

Figure 3.9. Monthly reference evapotranspiration (ET_O) and solar radiation (RS) during the 2015/16 and 2016/17 seasons compared to the long term mean (LTM) in Stellenbosch.

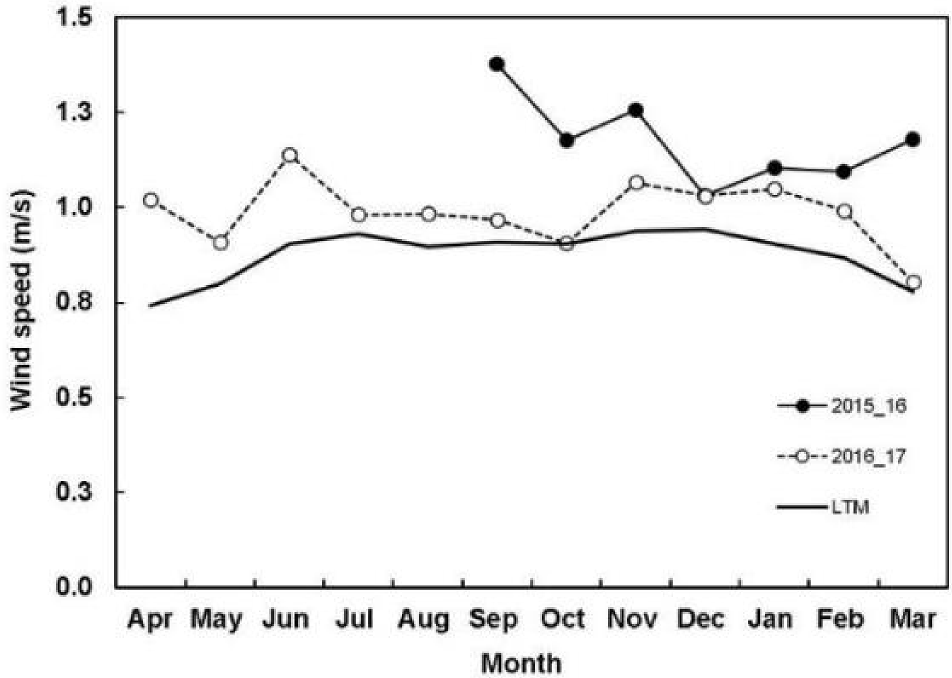

Figure 3.10. Average wind speed during the 2015/16 and 2016/17 seasons compared to the long term mean (LTM) in Stellenbosch.

3.3.2 Soil water status

2015/16 season: Due to the considerably low winter rainfall in 2015, the soil was relatively dry before the commencement of the 2015/16 growing season and before application of the mulches (Fig. 3.11). The soil water content (SWC) in the grapevine row under all treatments was *c.* 300 mm in early October during the early stages of the 2015/16 growing season, and gradually depleted until a rainfall event (11 mm) in January 2016 (Fig 3.11). The soils under each treatment dried out at the same rate. By March 2016, *i.e.* the post-harvest period, the total SWC of each treatment had been depleted to *c*.176 mm. In the following period, SWC remained at this level until the first substantial rain, *i.e.* 136 mm, occurred in June 2016. Thereafter, the SWC of all treatments increased substantially.

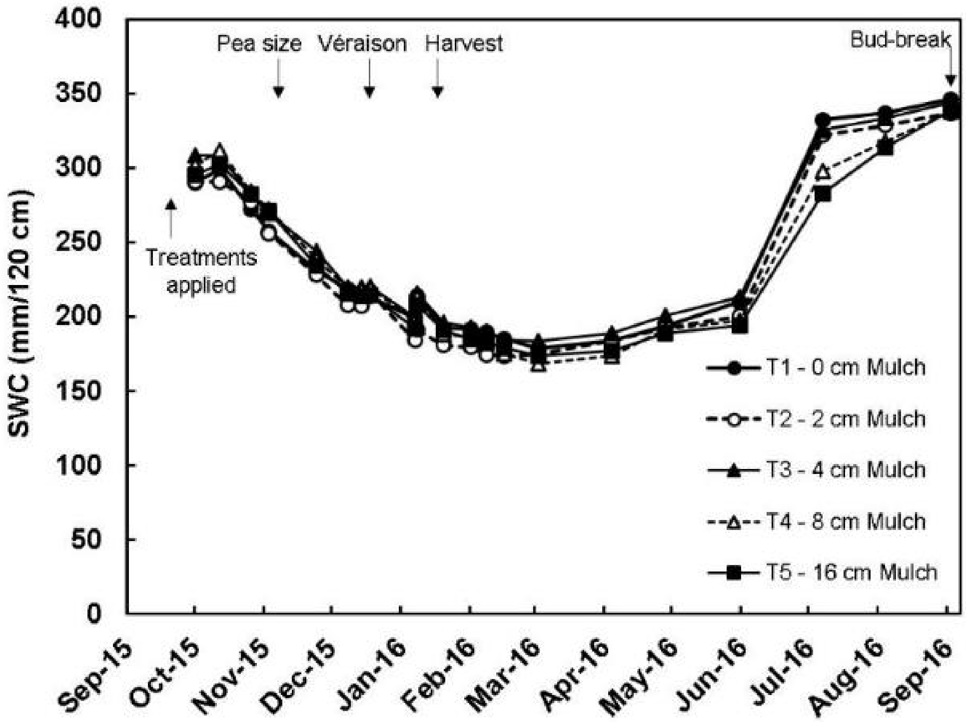

Figure 3.11. Effect of mulch thickness on total soil water content (SWC) in the 0-120 cm soil layer of the grapevine row during the 2015/16 season.

The SWC in the 0-30 cm soil layer depleted to *c*. 30 mm, whereas SWC in the 30-60 cm soil layer depleted to *c*. 45 mm (Figs. 3.12A & B). The SWC in these layers remained almost constant until mid-June 2016. The SWC of the 60-90 cm soil layer followed a similar pattern (Fig. 3.12C). The SWC of the 90-120 cm soil layer of all the treatments declined to *c*. 55-60 mm by January 2016 and remained at that level until late winter (Fig. 3.12D). As expected the SWC of the shallower soil layers, *i.e.* 0-30 cm and 30-60 cm remained at lower levels (Figs. 3.12A & B) than that of the deeper soil layers (Figs. 3.12C & D) during the first season. However, there were no significant differences between the SWC of the treatments at all depths. The mulch treatments, therefore, did not reduce evaporation from the soil surface compared to the bare soil. In a previous mulching study, 4 to 8 t/ha straw mulch did not substantially reduce evaporation compared to bare soil, particularly later in the season (Myburgh, 2013).

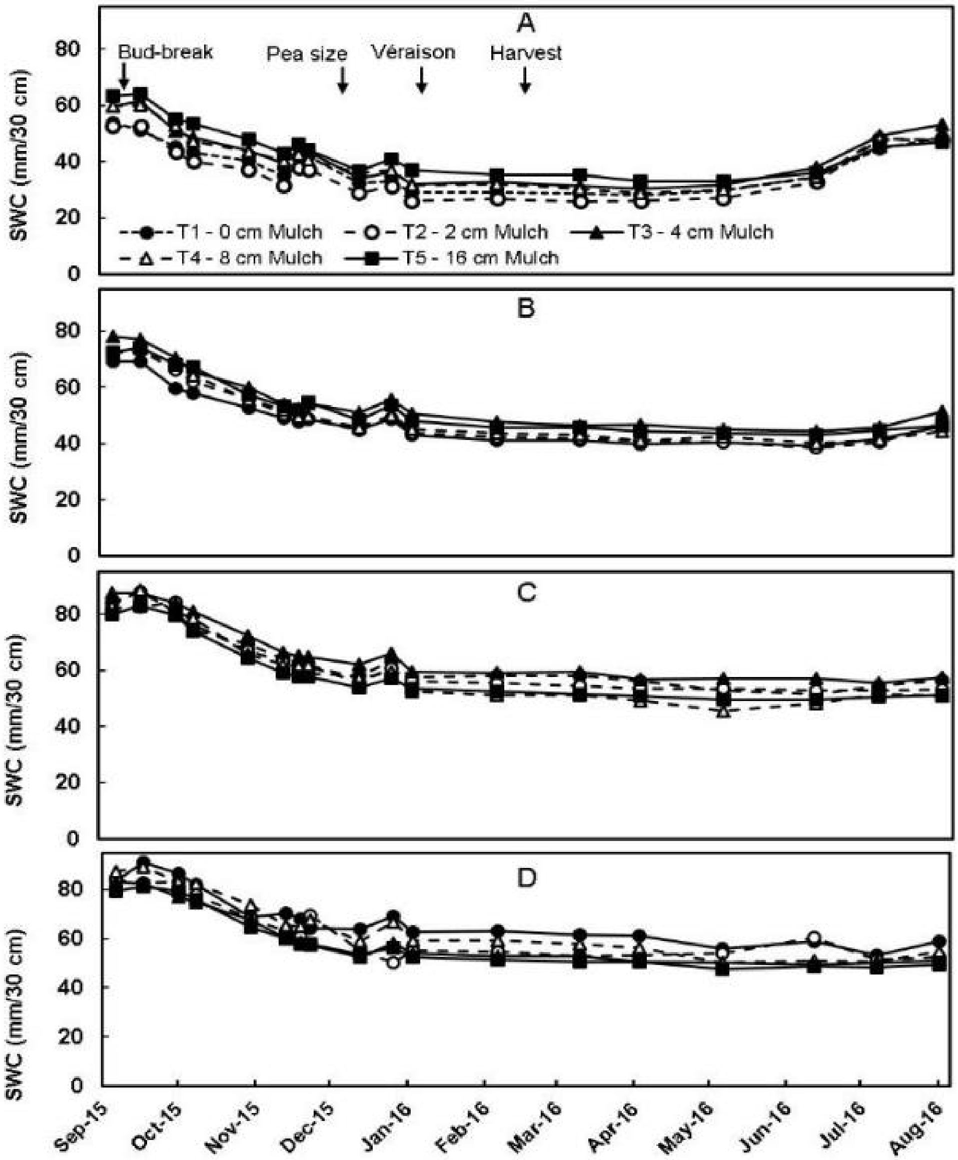

Figure 3.12. Effect of mulch thickness on temporal variation in soil water content (SWC) in the (A) 0-30 cm, (B) 30-60 cm, (C) 60-90 cm and (D) 90-120 cm soil layers of the grapevine row during the 2015/16 season.

2016/17 season: The total SWC at the start of the 2016/17 season ranged from 336 mm to 346 mm (Fig. 3.13), slightly higher than at the start of the 2015/16 season (Fig.3.11). The higher rainfall from July to September 2016 contributed to a higher total SWC at the start of the 2016/17 season compared to the 2015/16 season. Similar to the previous season, the SWC of all treatments declined at the same rate during the 2016/17 season. There were no significant differences in SWC between any of the mulch treatments and the control (Fig. 3.13). The SWC of the four layers (0-30; 30-60; 60-90 and 90-120 cm) in 2016/17 (Fig 3.14A to D) followed a similar pattern to 2015/16 (Fig. 3.12). In a previous study, 5 cm thick compost on the grapevine row increased SWC to a depth of 10 cm (Nugyen *et al*., 2013). Pinamonti (1998) also reported higher soil water content and reduced evaporation in response to municipal waste compost and sewage sludge compost mulches.

Despite no differences in SWC of the different treatments following the winter rain in June 2016, there was a tendency for the soils under the two thicker mulches, *i.e.* 8 cm (T4) and 16 cm (T5), to be drier than those under the control (T1) and thinner mulches of T2 and T3 (Fig. 3.15). Over the two wet winter months (June & July), the control (T1) and thinner mulches (T2 & T3) retained more soil water than the thicker mulches (T4 & T5). It would appear that the thicker mulches intercepted the rain and prevented downward movement of water to the soil until adequate rain fell by September 2016 to saturate the soil. There was an excellent correlation between the mulch thickness on the grapevine row and rain penetration into the soil (Fig. 3.16). Measurements taken before and immediately after a single major rain event confirmed that as the thickness of the mulch on the grapevine row increased, so the effectivity of the rainfall event decreased, *i.e.* depth of penetration into the soil, was reduced. These findings are in contrast to those reported by Ji and Unger (2001), in which straw mulches of 2 and 4 t/ha conserved soil water and increased the effectiveness of small precipitation events. The difference in soil water content reported in the previous study could be attributed to the material and different soil type.

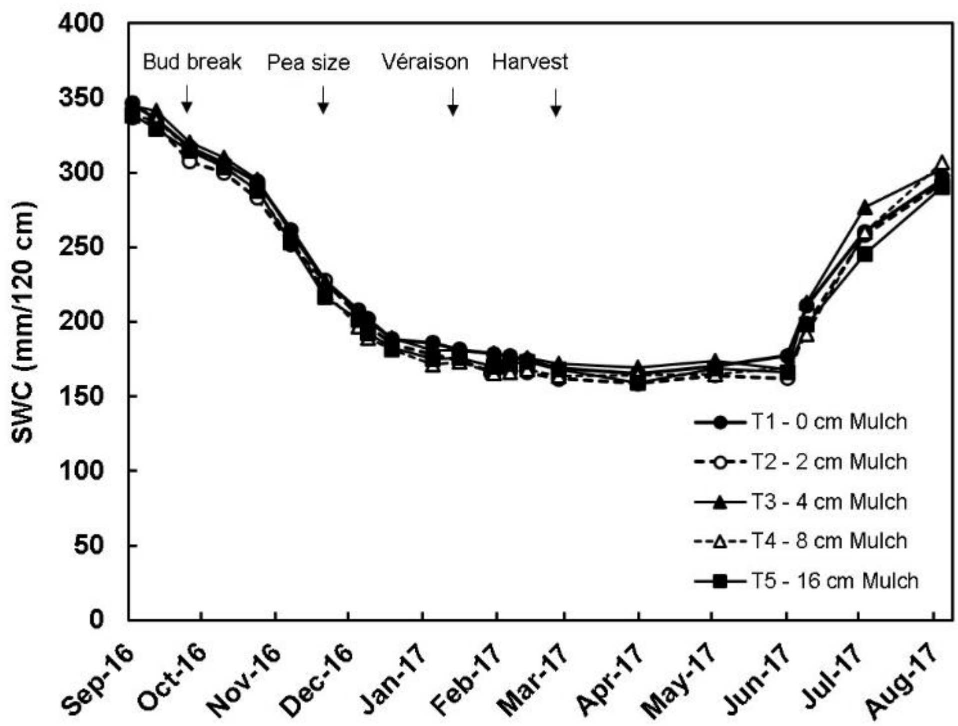

Figure 3.13. Effect of mulch thickness on total soil water content (SWC) in the 0-120 cm soil layer of the grapevine row during the 2016/17 season.

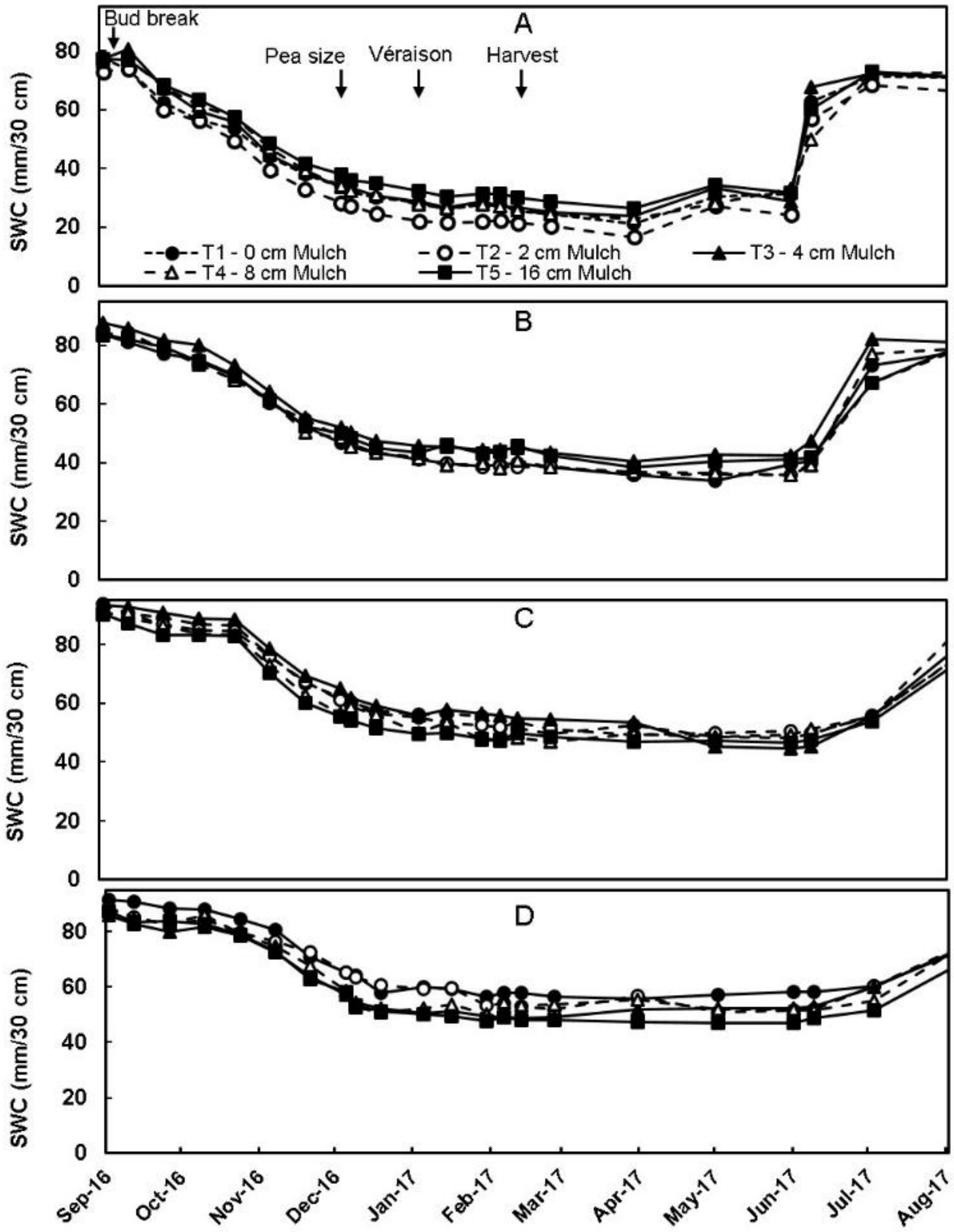

Figure 3.14. Effect of mulch thickness on temporal variation in soil water content (SWC) in the (A) 0-30 cm, (B) 30-60 cm, (C) 60-90 cm and (D) 90-120 cm soil layers of the grapevine row during the 2016/17 season.

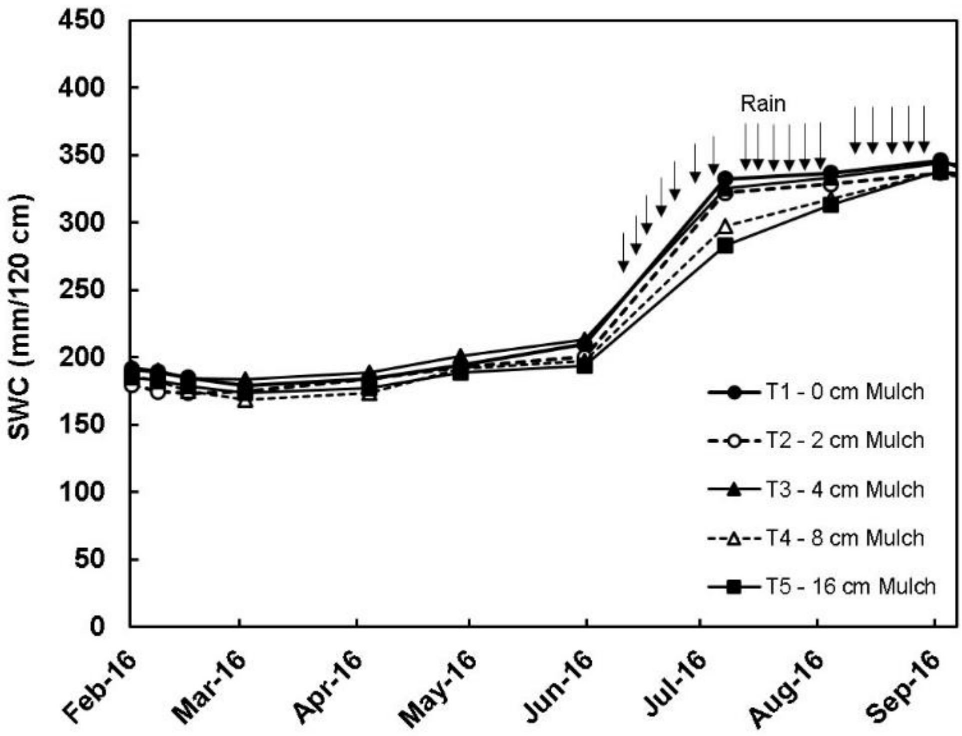

Figure 3.15. Effect of mulch thickness on soil water content (SWC) of the grapevine row from February 2016 to September 2016. Arrows indicate rainfall in excess of 5 mm.

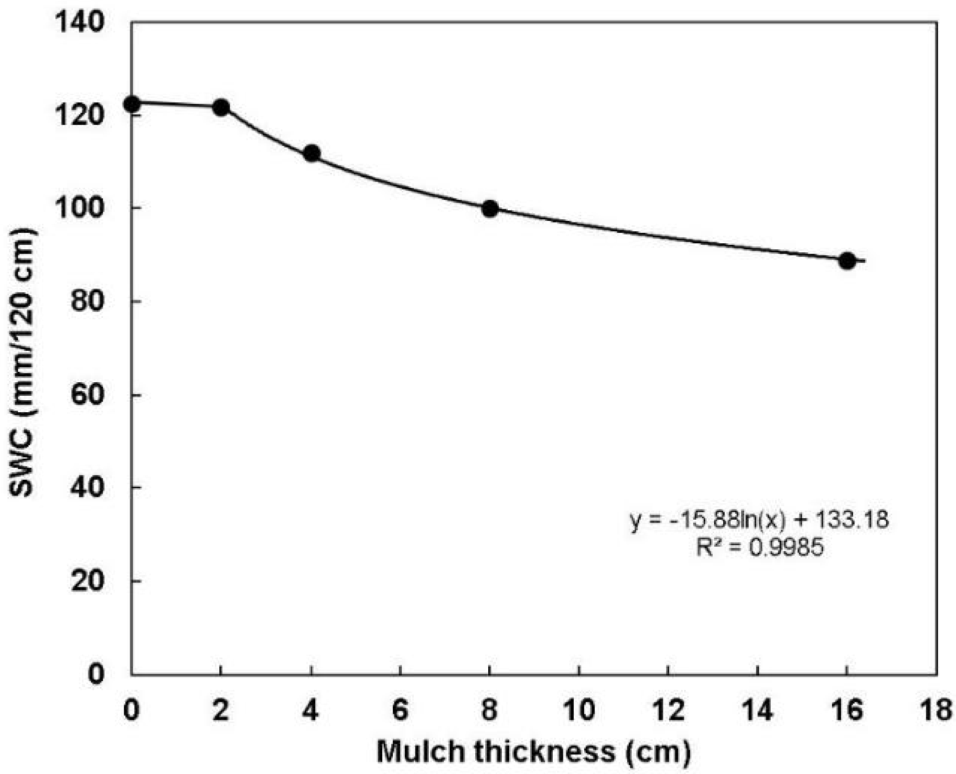

Figure 3.16. Effect of mulch thickness on rainfall penetration in the grapevine row between 31 May and 07 July 2016.

3.3.3 Water infiltration

Saturated hydraulic conductivity increased with compost mulch thickness (Fig. 3.17). Similar findings have been reported for straw mulch (Jordán *et al*., 2010). The relationship between mulch thickness and infiltration rate was best described using a second-order polynomial in which hydraulic conductivity significantly increased with mulch thickness to 16 cm, after which it was expected to plateau (Fig. 3.17). This trend suggested that thicker mulches than 16 cm would probably have no additional beneficial effects on water infiltration. It was also reported that infiltration rates under mulches improved, but that the intensity of rainfall events could affect infiltration rate under mulches (Montenegro, 2013).

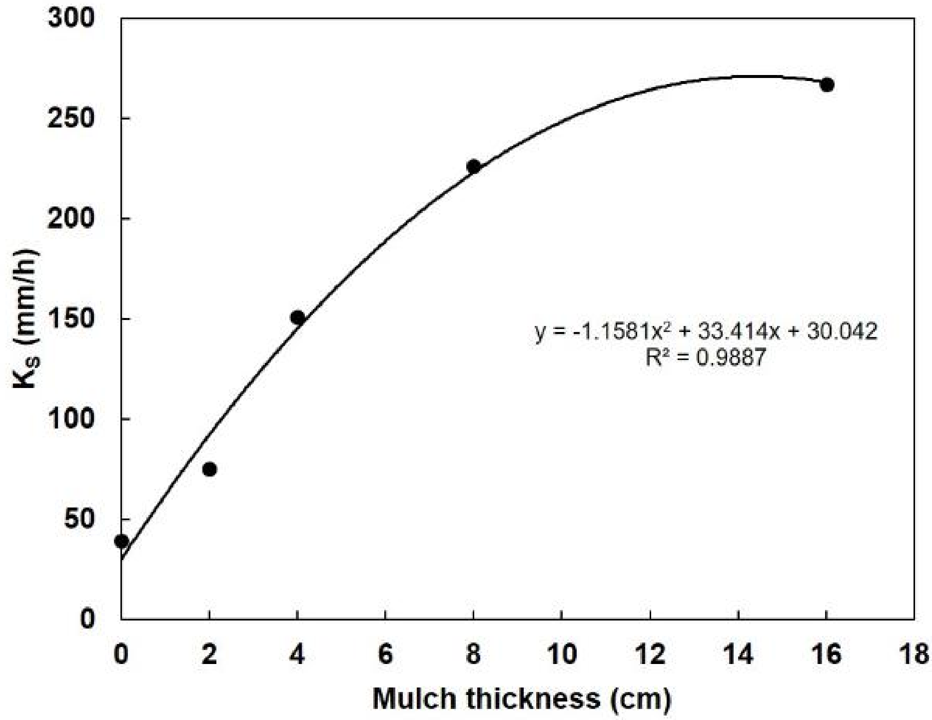

Figure 3.17. Effect of mulch thickness on near-saturation hydraulic conductivity (K_S) twenty-two months after application of the compost mulch.

3.3.4 Soil temperature

On cooler days, diurnal temperature amplitude was lower across all treatments (Fig. 3.18). The temperature of the soil under all treatments at the shallow depths (5 cm & 10 cm) showed greater fluctuations compared to the deeper soil layers (20 cm & 40 cm), particularly on warm days (Fig.3.19). No differences in soil temperature were observed under the mulch treatments compared to the control at all depths (data not shown). These findings are in contrast to those reported by Pinamonti (1998) and Cook (2006) where mulches resulted in reduced soil temperature and reduced soil temperature fluctuations.

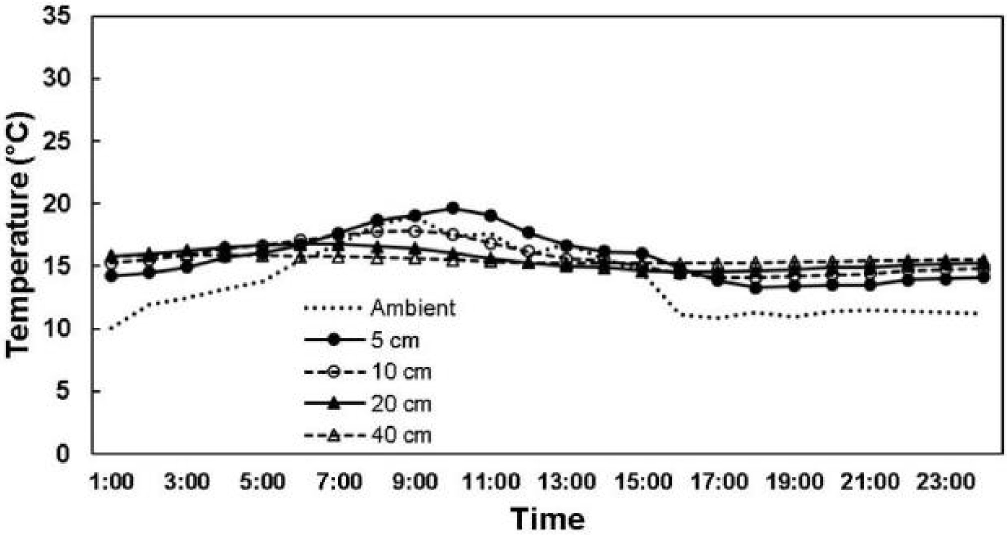

Figure 3.18. Temporal variation in ambient and soil temperature on a relatively cool day in September 2016.

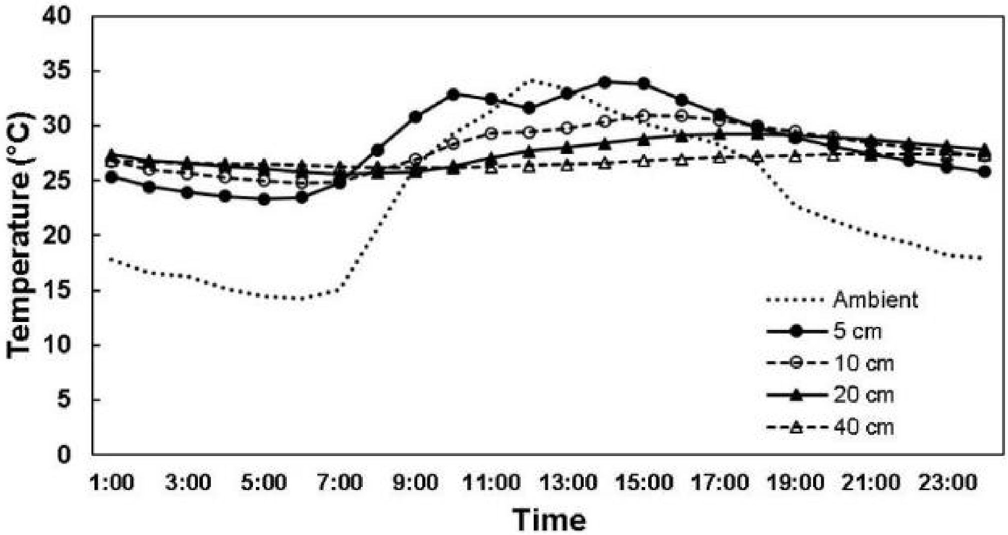

Figure 3.19. Temporal variation in ambient and soil temperature on a relatively warm day in January 2017.

3.3.5 Grapevine water status

2015/16 season: At flowering in early November 2015, the Ψ_S of mulched grapevines was approximately -0.57 MPa compared to -0.63 MPa of the control (Table 3.6). This indicated that none of the treatments experienced water deficits according to thresholds for water stress levels proposed by Van Leeuwen *et al.* (2009). According to the water constraint thresholds (Table 3.4) proposed by Lategan (2011), these values also fall under Class I, namely "no water constraints". By early December, grapevines under all treatments were still not experiencing water constraints. On 8 January 2016 (véraison), all grapevines experienced medium water constraints, with midday Ψ_S values ranging from -1.70 MPa to -1.90 MPa (Table 3.6). With the exception of T4, there were no differences in Ψ_S between mulch treatments during véraison. Measurements performed during the ripening period (in February before harvest) also revealed that there were no differences in Ψ_S between treatments and that all grapevines experienced severe water constraints. The compost mulch therefore had no effect on grapevine water status. Similarly, it was demonstrated that a compost mulch which was 5 cm thick and 60 cm wide applied to the grapevine row, had no effect on Ψ_S (Nguyen *et al*., 2013).

2016/17 season: Grapevine water status during the 2016/17 season followed a similar pattern to the previous season, with no water constraints experienced during the flowering and pea size berries period and medium water constraints in early January, around véraison (Table 3.7). All grapevines, regardless of the thickness of the mulch, experienced severe water constraints before harvest. There were also no differences in Ψ_S between mulch treatments compared to the control on any of the measurement dates. The different mulch treatments had no effect on the cumulative Ψ_S during the 2015/16 and 2016/17 seasons (Figs. 3.20 & 3.21). Under the prevailing climatic conditions, mulching therefore did not affect the grapevine Ψ_S compared to bare soil on the grapevine row.

When the Ψ_S data was related to the total SWC, there was a decrease in Ψ_S as the SWC decreased, *i.e.* became drier (Fig. 3.22). There was a good linear relationship between mean total SWC and mean Ψ_S during the 2016/17 season. Similar relationships were previously described for grapevines (Williams & Aruajo, 2002; Bruwer, 2010; Myburgh, 2011; Lategan, 2011).

Table 3.6. Effect of different mulch levels on midday stem (Ψ_S) water potential in Shiraz/101-14Mgt near Stellenbosch during the 2015/16 season.

Treatment	Ψ_S (MPa)			
	03 Nov	08 Dec	08 Jan	8 Feb
T1 - Control	-0.63 a[(1)]	-0.95 a	-1.70 b	-2.15 a
T2 - 2 cm Mulch	-0.58 a	-1.06 a	-1.71 b	-1.95 a
T3 - 4 cm Mulch	0.57 a	-1.01 a	-1.74 b	-2.19 a
T4 - 8 cm Mulch	0.56 a	-1.01 a	-1.90 a	-2.16 a
T5 - 16 cm Mulch	0.58 a	-0.99 a	-1.75 b	-2.25 a

[(1)] Values designated by the same letters within a column does not differ significantly ($p \leq 0.05$).

Table 3.7. Effect of different mulch levels on midday stem (Ψ_S) water potential in Shiraz/101-14Mgt near Stellenbosch during the 2016/17 season.

Treatment	Ψ_S (MPa)			
	07 Nov	05 Dec	16 Jan	06 Feb
T1 - Control	-0.56 ab[(1)]	-0.96 a	-1.89 a	-2.01 a
T2 - 2 cm Mulch	-0.55 ab	-1.03 a	-1.79 a	-2.01 a
T3 - 4 cm Mulch	-0.60 ab	-0.91 a	-1.89 a	-2.08 a
T4 - 8 cm Mulch	-0.68 a	-1.01 a	-1.41 a	-2.08 a
T5 - 16 cm Mulch	-0.53 b	-1.03 a	-1.96 a	-2.05 a

[(1)] Values designated by the same letters within a column do not differ significantly ($p \leq 0.05$).

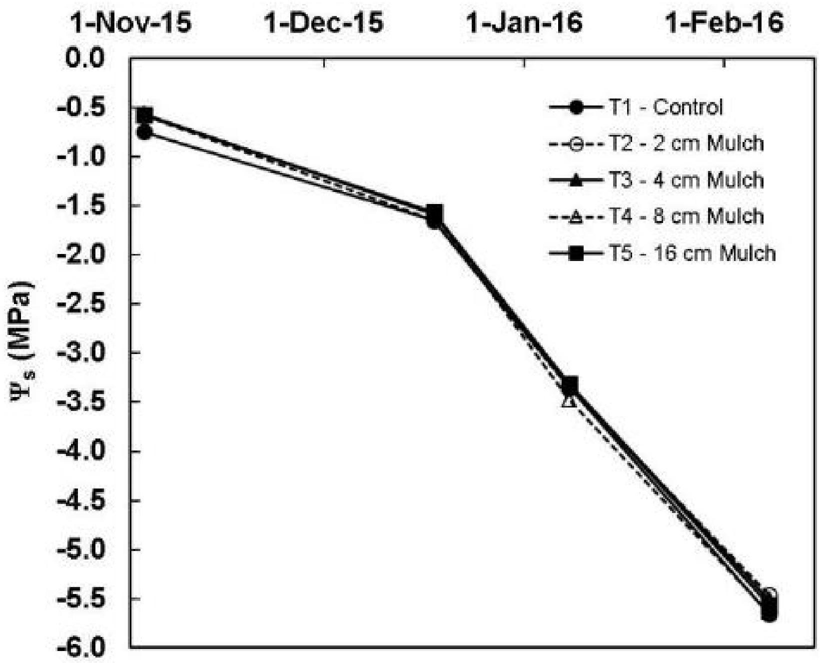

Figure 3.20. Effect of mulch thickness on cumulative midday stem (Ψ_S) water potential in Shiraz/101-14 Mgt in a Dundee soil near Stellenbosch during the 2015/16 season.

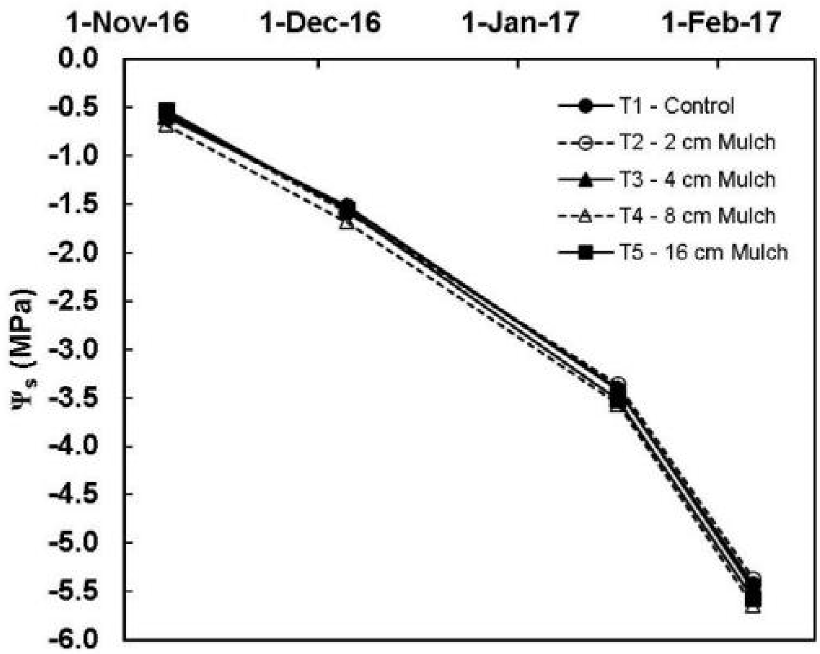

Figure 3.21. Effect of mulch thickness on cumulative midday stem (Ψ_S) water potential in Shiraz/101-14 Mgt in a Dundee soil near Stellenbosch during the 2016/17 season.

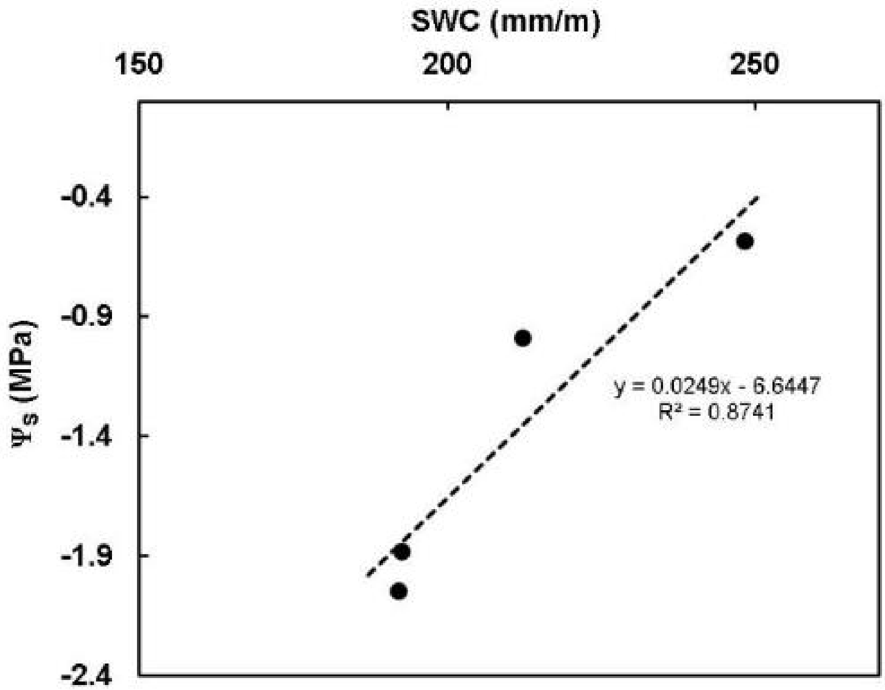

Figure 3.22. Relationship between mean midday stem water potential (Ψs) and total soil water content (SWC) in Shiraz/101-14 Mgt in a Dundee soil near Stellenbosch in the 2016/17 season.

3.3.6 Vegetative growth

The different mulch treatments did not have any effect on mass per cane compared to the control in 2016 and 2017. In 2016, pruning mass of grapevines under the thickest mulch, *i.e.* T5, was higher compared to that of grapevines without mulch (T1) and under the 2 cm (T2) mulch (Table 3.8). An increase in vegetative growth was only observed in the first season, where the thickest mulch, 16 cm, was applied. (Table 3.8). Likewise, full surface straw mulches of 4 to 12 t/ha did not increase vegetative growth (Myburgh, 2013). Cane mass was comparable to values reported for irrigated Shiraz/110R near Robertson (Stolk, 2014). Results from the current study are supported by those of Van Huyssteen and Weber (1980b) in which a full surface straw mulch positively affected the pruning mass of dryland Chenin blanc grapevines compared to chemical weed control, clean cultivation, shallow and deep trench furrows and permanent sward. Had the compost been applied as a full surface mulch as opposed to a mulch on the grapevine row, the effect of the mulch on grapevine vegetative growth may have been more pronounced. Vegetative growth therefore responded positively to increasing mulch thickness during the first season after mulch application, irrespective of the abnormally dry winter preceding the 2015/16 season (Fig. 3.8) and the absence of Ψ_S and SWC differences. The absence of differences in the 2017 cane mass may be attributed to a cumulative effect of the drought or perhaps the degree of weathering of the mulch.

Table 3.8. The effect of different mulch thicknesses on the pruning components of a Shiraz/101-14 Mgt vineyard near Stellenbosch during 2016 and 2017.

Year	0 cm Mulch (T1)	2 cm Mulch (T2)	4 cm Mulch (T3)	8 cm Mulch (T4)	16 cm Mulch (T5)
			Mass per cane (g)		
2016	33.49 a	39.14 a	44.13 a	39.46 a	40.83 a
2017	37.02 a	43.00 a	36.62 a	39.67 a	35.80 a
			Cane mass per grapevine (kg)		
2016	0.51 b	0.60 b	0.64 ab	0.66 ab	0.77 a
2017	0.63 a	0.73 a	0.77 a	0.68 a	0.61 a
			Pruning mass (t/ha)		
2016	1.26 b	1.48 b	1.58 ab	1.64 ab	1.91 a
2017	1.54 a	1.81 a	1.64 a	1.70 a	1.50 a

(1) Values designated by the same letters within a row do not differ significantly ($p \leq 0.05$).

3.3.7 Yield

Mulch thickness had no effect on berry size during both seasons (Table 3.9). In 2016, grapevines under the two thicker mulches (T4 & T5) had more berries per bunch compared to grapevines without mulch (Table 3.9). In 2017 however, the number of berries per bunch for only the thickest mulch (T5) was s higher than the control. Bunch mass of the 16 cm mulch (T5) was higher than the control in 2016 but there were no differences in bunch mass in 2017 (Table. 3.9). Mulch thickness did not affect grapevine fertility *i.e.* bunches per grapevine, compared to the control during both seasons. Since there were no differences in grapevine water status, this was to be expected. Yield per grapevine (kg) was significantly higher under the thickest mulch (T5) than the bare soil control during both seasons (Table. 3.9). Bunch mass, number of berries per bunch and yield were slightly higher overall during the 2016/17 season compared to the 2015/16 season. The slightly lower yield in 2016 may be attributed to the lower than average rainfall in 2015/16 and the unexpectedly high temperatures experienced in January 2016 (Fig. 3.6). On the other hand, where a high compost mulch rate (153 m^3/ha) was applied to low yielding irrigated grapevines, yield increased, even in a particularly dry season (Chan *et al.,* 2010). In another study, it was reported that the application of full surface straw mulches consisting of 4 t/ha, 8 t/ha and 12 t/ha, respectively, had no effect on yield of irrigated Sauvignon blanc grapevines near Stellenbosch, compared to bare soil (Myburgh, 2013).

Table 3.9. Yield and its components for Shiraz grapevines measured in four experiment plots in a vineyard near Stellenbosch during the 2015/16 and 2016/17 seasons.

Season	0 cm Mulch (T1)	2 cm Mulch (T2)	4 cm Mulch (T3)	8 cm Mulch (T4)	16 cm Mulch (T5)
			Mass per berry (g)		
2015/16	1.12 a[(1)]	1.22 a	1.16 a	1.09 a	1.14 a
2016/17	1.30 a	1.24 a	1.24 a	1.12 a	1.13 a
			Berries per bunch		
2015/16	68 b	77 ab	81 ab	86 a	88 a
2016/17	71 b	85 ab	82 ab	95 ab	101 a
			Bunch mass (kg)		
2015/16	763 b	939 ab	943 ab	950 ab	987 a
2016/17	936 a	1029 a	1033 a	1094 a	1149 a
			Bunches per grapevine		
2015/16	29. a	28 a	31 a	32 a	32 a
2016/17	28 a	28 a	30 a	30 a	34 a
			Yield per grapevine (kg)		
2015/16	2.3 b	2.6 ab	2.9 ab	2.9 ab	3.1a
2016/17	2.6 b	2.9 ab	3.1 ab	3.3 ab	3.9 a
			Yield (t/ha)		
2015/16	5.5 b	6.3 ab	7.2 ab	7.2 a	7.7 a
2016/17	6.4 b	7.2 ab	7.7 ab	8.1 ab	9.6 a

(1) Values designated by the same letter within a row do not differ significantly ($p < 0.05$).

3.3.8 Juice characteristics

Mulch thickness consistently had no effect on juice TSS, TA and pH compared to the un-mulched control (Table 3.10). During both seasons, the different mulch treatments also did not affect berry size development compared to the bare soil control. Juice TA levels tended to be slightly higher, and pH levels lower during the 2016/17 season compared to the 2015/16 season. In 2015/16 and 2016/17 the mean sugar content was 241.7 ± 3.1 mg/mL and 242.9 ± 3.1 mg/mL respectively. Mulch thickness did not affect the sugar content during both seasons (data not shown). In 2015/16 and 2016/17 the mean sugar content per berry was 251.8 ± 7.5 mg/berry and 367.9 ± 19.6 mg/berry, respectively. The mulch treatments had no effect on sugar content per berry during both seasons (data not shown). The slightly higher TA and lower pH of the juice in 2016/17 may have been due to higher than usual rainfall in January 2017 compared to the LTM (Fig 3.8), which may have prevented dehydration of the berries to some extent. The unusually high ambient temperatures in January 2016 (Fig. 3.6) as well as lower relative humidity and higher evapotranspiration (Fig. 3.7), may also have contributed to less favourable ripening conditions in 2016, leading to poorer berry condition at harvest. Mulch thickness therefore had no effect on overall berry quality during both seasons.

Table 3.10. Effect of different mulch levels on total soluble solids (TSS), total titratable acidity (TA), pH, berry volume and sugar contents in Shiraz/101-14Mgt grapes near Stellenbosch during the 2015/16 and 2016/17 seasons.

Season	T1- Control	T2 - 2 cm Mulch	T3 - 4 cm Mulch	T4 - 8 cm Mulch	T5 - 16 cm Mulch
			Harvest date		
2015/16			15 February 2016 (23-24°B)		
2016/17			21 February 2017 (23-25.5°B		
			TSS (˚B)		
2015/16	24.5 a[(1)]	23.9 a	24.3 a	24.0 a	24.2 a
2016/17	25.4 a	24.0 a	24.0 a	24.2 a	24.2 a
			TA (g/L)		
2015/16	5.01 a	5.04 a	4.91 a	4.99 a	5.02 a
2016/17	5.34 a	5.61 a	5.58 a	5.77 a	5.62 a
			pH		
2015/16	3.90 a	4.02 a	3.93 a	4.08 a	4.09 a
2016/17	3.71 a	3.65 a	3.73 a	3.61 a	3.72 a
			Berry volume (cm^3)		
2015/16	1.02 a	1.10 a	1.05 a	1.00 a	1.04 a
2016/17	1.19 a	1.15 a	1.14 a	1.02 a	1.03 a

(1) Means followed by the same letter within a row do not differ significantly ($p < 0.05$).

3.3.9 Wine characteristics

There were no differences in the wine sensorial characteristics between treatments in the preliminary tasting. Consequently, no detailed sensory evaluation was carried out on the wines. This was to be expected since visual observations indicated that there were no obvious differences in bunch exposure to the extent that the treatments would influence wine quality.

3.3.10 Weathering of the mulch

After twenty months, only remnants of the 2 cm (T2) and 4 cm (T3) compost mulch treatments were visible on the grapevine row (Fig.3.22 & 3.23). The 8 cm (T4) and 16 cm (T5) had weathered to *ca.* 3 cm and 6 cm, respectively.

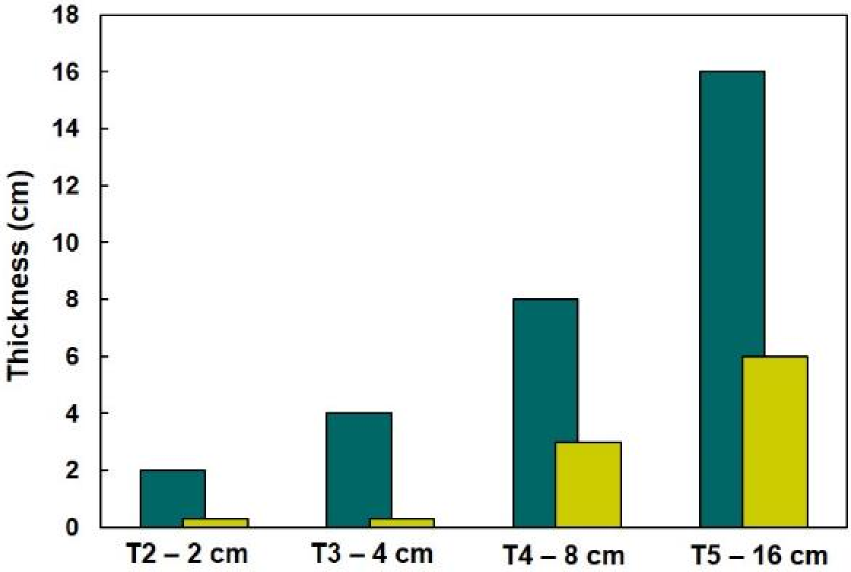

Figure 3.22. Mulch thickness at application and after twenty months.

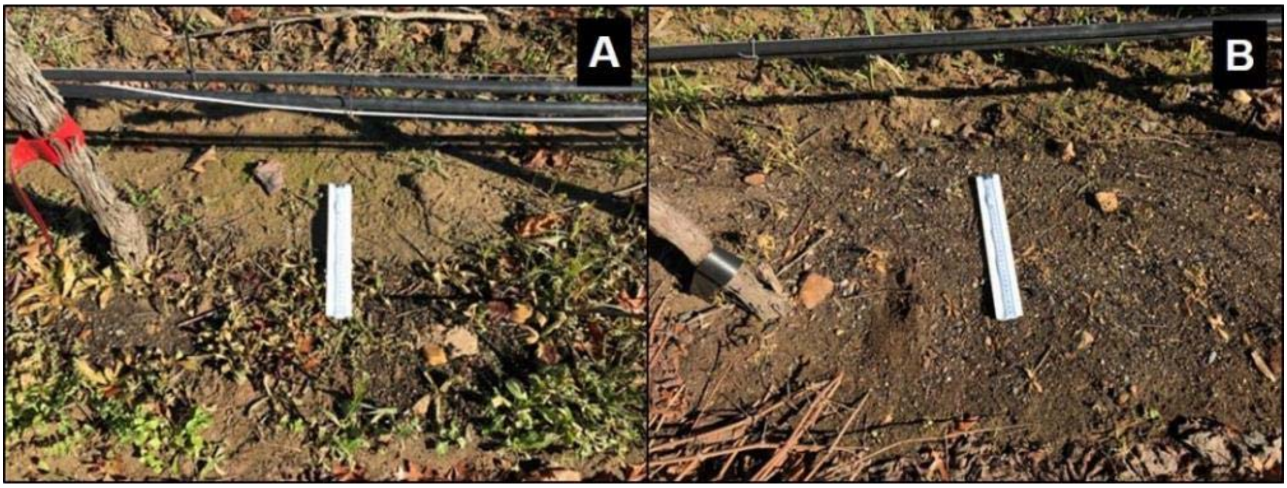

Figure 3.23. The mulch remaining in the 2 cm (A) and 16 cm (B) treatments, approximately 20 months after application to the grapevine row. A 30 cm ruler was placed on the mulch for scale.

3.4 Conclusions

Results showed that the application of mulch on the grapevine row to a height of 16 cm above the soil surface did not affect the SWC throughout the profile compared to bare soil. The 0-30 cm soil layer exhibited greater SWC fluctuations than deeper layers, but there were no differences between treatments. The thicker mulches appeared to intercept the smaller quantities of rain, thereby reducing the effectiveness of small rainfall events. Water infiltration rate, however, responded positively to mulch thickness. Therefore, it could possibly be that, under normal rainfall conditions, or in the case of heavier rainfall events, increased infiltration rates could lead to higher SWC under the thicker mulches. It was also noted that high numbers of fine roots developed close to the surface under the thicker mulch layers. After approximately two years, only remnants were visible on the grapevine row where the mulch thickness was 4 cm or less. Over the same period, the 8 cm and 16 cm mulches had weathered to *c*. 3 cm and 6 cm, respectively.

Even under the relatively dry conditions, mulch had no effect on grapevine Ψ_S, irrespective of the thickness. This was to be expected since the mulching had no effect on the soil water content. However, vegetative growth and grapevine yield responded positively to mulch thickness on the grapevine row during both seasons. The fine roots observed under the mulches could have contributed to the improved growth and yield. In contrast to grapevine growth and yield, mulching had no effects on juice and wine quality characteristics.

A full surface application may induce a positive effect on SWC, but the costs incurred would not be economically viable. During periods of abnormally low rainfall, the application of mulch can be recommended as a short term solution to prevent possible yield losses. Given the positive response of grapevine vegetative growth and yield to the 16 cm mulch, it could have benefits for vineyards where low vigour or yield is a concern, particularly in dryland cultivation. Coarser, more durable material such as bark or wood chips may be better buffered against weathering.

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Chapter 4

Research results

The effects of root pruning and the furrow plough with compost on soil conditions

CHAPTER IV: THE EFFECTS OF ROOT PRUNING AND THE FURROW PLOUGH WITH COMPOST ON SOIL CONDITIONS

4.1 Introduction

Various factors contribute to grapevine performance such as adequate root development and distribution (Van Zyl & Van Huyssteen, 1984; Hunter & Le Roux, 1992), the balance between above- and below ground growth (Saayman & Van Huyssteen, 1980, Hunter, 1998), availability of nutrients and water, soil chemical status, diseases and climatic conditions (Conradie *et al.*, 2002). Root development and water availability are strongly related to soil physical conditions. Compact soils with surface crusting inhibit water infiltration into the soil and impede root development (Saayman, 1982). Soil organic matter (SOM) may increase porosity and decrease bulk density (Magdoff & Weil, 2004) and therefore provides soils with a degree of resistance to compaction (Cass & McGrath, 2005). Previous studies have shown increased infiltration (Martens & Frankenberger, 1992) and/or water holding capacity in response to increased soil organic carbon (SOC) (Franzleubbers, 2002).

Before the emergence of inorganic fertilizers, the use of manures or compost in vineyards was common (Jackson, 2008). The low costs and accessibility of inorganic fertilizers and the increase in large-scale farming led to widespread use of inorganic fertilizers. Since compost is variable in composition, it is considered an ineffective replacement for fertilizers. Increased awareness about ground water pollution, soil degradation, diminishing humus content, the contribution of soil organic matter and biological activity to soil fertility has led to increased interest in compost application in vineyards and other crops. Some of the benefits of compost include increased SOM, improved aggregate stability and microbiological activity (Roldán *et al*., 1996). Soil organisms are responsible for the cycling of nutrients found in plant residues and organic amendments, thereby facilitating nutrient availability through mineralisation (Magdoff & Weil, 2004). Soil microbes, which live on humus, are a food source for earthworms. Soil porosity, aeration, water infiltration and -retention are facilitated by earthworm activity (Jackson, 2008). Therefore, the use of compost is aimed at improving overall soil conditions, rather than replacing fertilizers. In addition to the cost, consideration must be given to the composition. A compost containing high quantities of manure can cause excessive vegetative growth due to excessive N released into the soil. Apart from the incorporation of compost during vineyard preparation, there is little scientific knowledge on its application after vineyard establishment. Since the largest portion of OM is found near the soil surface, soils on slopes tend to lose more OM through erosion than soils on flat terrain. Mulches are not suitable for vineyards on slopes due to the risk of erosion, therefore OM incorporation should be considered in such cases. The furrow plough is an implement that was used in the past to incorporate grapevine prunings into the soil (Burger & Deist, 1981). Very recently, agricultural innovation has led to the development of trailers combined with a ploughing implement, enabling the compost to be simultaneously deposited and incorporated. Root pruning by deep tillage was a relatively common practice in previous years, particularly in South Africa, to improve grapevine growth while alleviating compaction (Van Zyl & Van Huyssteen, 1987). It has also been applied in vigorous vineyards as a form of vegetative growth control. The theory behind the root pruning was the stimulation of root growth where roots had been severed to enhance root distribution and the volume of root-colonisable soil. The decreased compaction should allow for better water movement in the soil and water availability to the roots. However, regular and severe root pruning was shown to reduce growth and yield of irrigated Colombar grapevines (Saayman & Van Huyssteen, 1983).

This study set out to evaluate the effect of root pruning, with and without compost, on soil conditions, when used as a management practice to improve grapevine performance in a sloped vineyard where mulching would be impractical. The furrow plough was included as a comparative method of compost incorporation.

4.2 Materials and Methods

4.2.1 Vineyard characteristics

The field trail was carried out in a 21-year old Pinotage/110Richter vineyard on the Welgevallen experiment farm in Stellenbosch in the Coastal grape growing region of the Western Cape. The vineyard was managed without supplementary irrigation since establishment in 1994. The climate of the region is considered Mediterranean, and based on the growing degree days (GDD) from September until March (Winkler *et al.*, 1974), the specific locality represents a class IV climatic region (Le Roux, 1974). The grapevines were spaced 2.7 × 1.4 m and trained on a vertical shoot position system with a unilateral cordon and 5 spurs per arm (Booysen *et al.*, 1992). The vineyard is on a WSW-facing slope with a N-S row orientation. The characteristics of the vineyard are given in Table 4.1.

Table. 4.1. Characteristics of the vineyard where the tillage and compost treatments were applied.

Descriptor	Vineyard details
Climate	Mediterranean
Locality	Welgevallen experiment farm
Lat/Long	33.9515°S, 18.8737° E
Elevation	*c*. 210 m a.s.l.
Terrain	Sloped
Scion	Pinotage (clone RQ28B)
Rootstock	Richter 110 (*Vitis riparia* x *Vitis rupestris*)
Grapevine spacing	2.7 x 1.4 m
Trellis/training system	Four strand Lengthened Perold with a unilateral cordon
Pruning system	Two bud spurs
Irrigation	Dryland

4.2.2 Treatments

In September 2015, after adequate rain had fallen to sufficiently wet the soil to 120 cm, six tillage treatments were applied with a control (Table 4.2). The treatments included a control (no tillage & no compost); furrow plough on one side of the grapevine row with compost incorporation (Alt rows FP+comp), furrow plough on both sides of the grapevine row with compost incorporation (All rows FP+comp), root pruning/deep tillage without compost on one side of the row (Alt rows RP) and both sides of the row (All rows RP), root pruning/deep tillage with compost on one side of the row (Alt rows RP+comp) and both sides (All rows RP+comp).

The furrow plough treatment was applied by means of a furrow plough (*vlekploeg*) implement (Fig. 4.1A). The implement was used to create a furrow or trench in the middle of the work row of *c*. 15-30 cm deep (Fig. 4.1B). Compost was deposited in the furrow and subsequently covered with soil by hand (Fig. 4.1C & D). A small excavator was employed to carry out the root pruning since the vineyard was located on a slope and rows were narrow (Fig. 4.2A). The bucket of the excavator was 80 cm in length and worked the soil to a depth of *ca.* 60 cm between the tractor wheel tracks (Fig.

4.2A). The root pruning with compost treatment was applied in the same manner after 57 t/ha (dry weight) compost was deposited in the work row (Fig 4.2B). The compost was then incorporated during the root pruning action (Fig. 4.2C).

The compost was produced by a static windrow method and matured for six months before being applied to the vineyard. The compost comprised of grape marc, wheat straw, sheep manure, horse manure, cow manure, tomato plants and root shavings, and citrus waste. A compost sample was analysed by two commercial laboratories (Elsenburg Agricultural Laboratory, Stellenbosch and Bemlab, Strand) before being applied to the vineyard and analysed for pH, resistance, moisture, density, N, P, K^+, Ca^{2+}, Mg^{2+}, Na^+, Mn^{2+}, Fe^{2+}, Cu^{2+}, Zn^{2+}, B^{3+}, C, NH_4-N and NO_3-N. Except for the Fe^{2+} and ash content which were high, the composition was considered comparable to informal industry standards (Table 4.3). However, no explanation could be found for the high Fe^{2+} and ash content.

Table 4.2. Tillage and compost treatments applied in September 2015.

Treatment no.	Treatment	Description
1	Control	No tillage, no compost
2	Alt rows FP+comp	Furrows alternate rows, with compost 57 t/ha
3	All rows FP+comp	Furrows every row, with compost 57 t/ha
4	Alt rows RP	Root pruning alternate rows, no compost
5	All rows RP	Root pruning every row, no compost
6	Alt rows RP+comp	Root pruning alternate rows, with compost 57 t/ha
7	All rows RP+comp	Root pruning every row, with compost 57 t/ha

Table 4.3. Table presenting compost analysis prior to application in September 2015.

Compost variable	Value
pH	6.8
Resistance (ohm)	90
Moisture (%)	33.5
Density (kg/m^3)	796.7
N (%)	0.92
P (%)	0.38
K^+ (%)	0.42
Ca^{2+} (%)	2.9
Mg^{2+} (%)	0.2
Na^+ (mg/kg)	844.08
Mn^{2+} (mg/kg)	279.58
Fe^{2+} (mg/kg)	13848.9
Cu^{2+} (mg/kg)	20.59
Zn^{2+} (mg/kg)	134.67
B^{3+} (mg/kg)	12.18
C (%)	12.44
Ash (%)	74.9
NH_4-N (mg/kg)	1.69
NO_3-N (mg/kg)	20.23

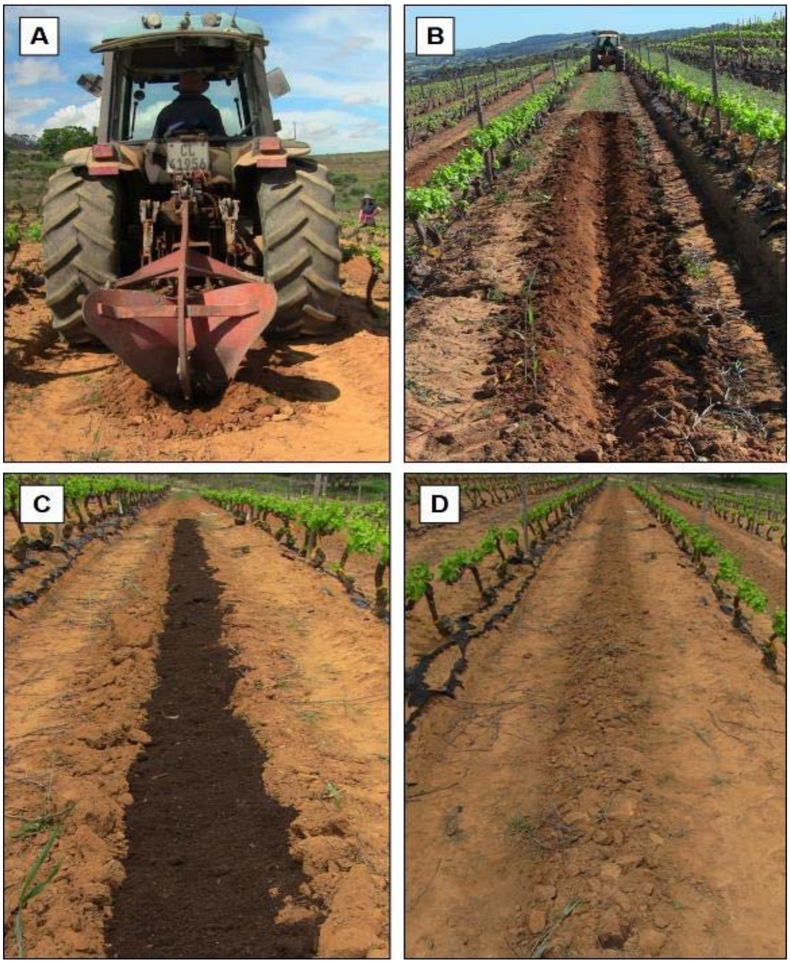

Figure 4.1. (A) Furrow plough implement used to create (B) furrows in the work row before (C) compost was deposited and (D) covered by hand.

Figure 4.2. The (A) small excavator used to carry out the root pruning action and (B) compost deposited in the work row before being (C) incorporated.

4.2.3 Experiment layout

Six localities representing low, medium and higher vigour were selected based on high-spatial resolution information, supplied by an airborne image (Normalised Difference Vegetation Index, NDVI) taken in February 2013 (Fig. 4.3). The location of each plot was then confirmed or adjusted after assessing grapevine above-ground growth by visual inspection and long term vegetative expression by means of trunk circumference measurements. The treatments were replicated in each of the six major plots distributed across the vineyard (Fig.4.4 & 4.5).

Figure 4.3. Locality of the six replications consisting of four experiment major plots within the Pinotage vineyard on the lower slopes of the Stellenbosch Mountain.

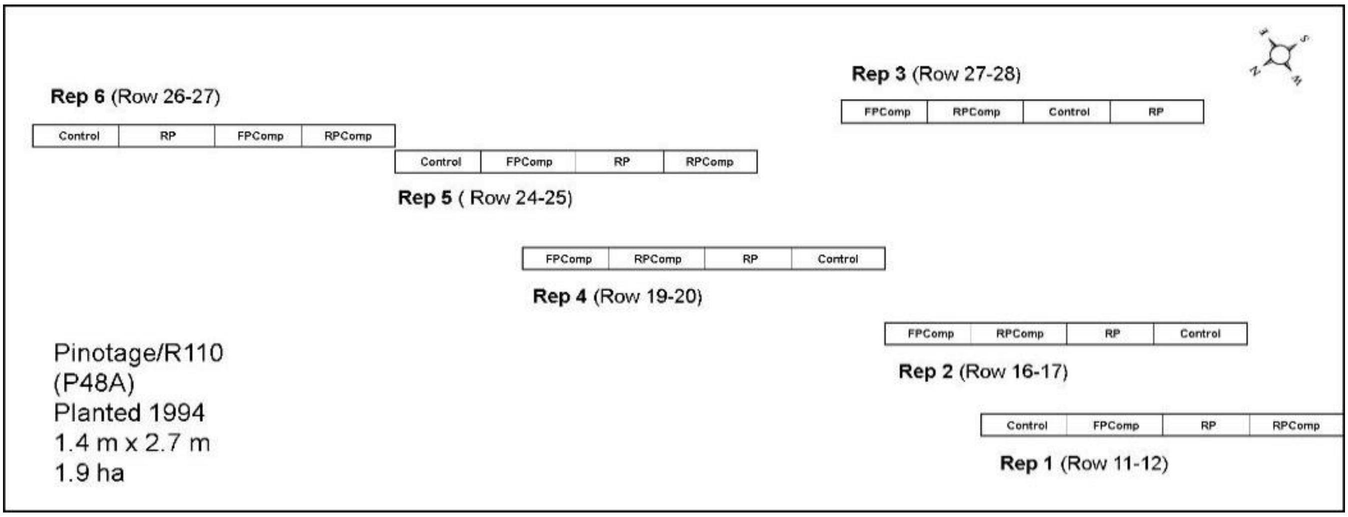

Figure 4.4. Distribution of the six major replications within the Pinotage/R110 vineyard.

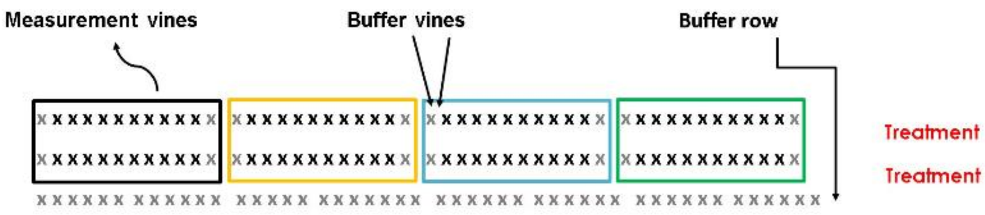

Figure 4.5. Example of the treatment plot layout within a replication.

4.2.4 Measurements

4.2.4.1 Atmospheric conditions

The region's climate was described using long term air temperature, relative humidity (RH), reference evapotranspiration (ET_0), rainfall, wind speed and incoming solar radiation (insolation) data collected from the Fleurbaix weather station (33˚9591'S,18˚8337'E,125 m mean height above sea level) in Stellenbosch. The data was obtained from the ARC Institute for Soil Climate and Water in Pretoria (Refer to Chapter 3, Tables 3.11 to 3.13). The long term data was used to compare the atmospheric conditions during the 2015/16 season and 2016/17 season to the long term mean (LTM) and to classify the climate of the area on a macro climatic scale. The mean data from the weather station was used to calculate the Winkler Index for the experiment site. Since the Fleurbaix station was transitioning from a mechanical to an automatic station, data was not available from April to August 2015. In order to determine rainfall for this period, rainfall data from a rain gauge at Nietvoorbij was used to estimate the rainfall at the Fleurbaix station.

4.2.4.2 Water infiltration

Water infiltration was quantified in the middle of the work row by means of the constant head method (Bouwer, 1986). A single metal ring with a diameter of 200 mm was driven 50 mm into the soil in the work row, ensuring as little disturbance to the soil as possible. A spirit-level was used to ensure the rings were level. Water used to irrigate the other blocks on the farm was used for the measurements. Initially 2 L of water was poured onto a sponge inside the cylinder in order to saturate the soil. The sponge was used to break the stream of water and protect the soil against erosion. A calibrated, stoppered cylinder with a Mariotte syphon supplied water to the infiltrometer. One tube was inserted through the stopper to siphon water to the infiltrometer (ring) and another allowed air into the bottle. The level on the cylinders was recorded every two minutes whilst a constant water level was maintained inside the ring. The rate of the decline of the water in the cylinder was used to calculate infiltration rate. Infiltration was measured in every experiment plot. Three measurements were carried out per plot.

4.2.4.3 Soil water content

Soil water content (SWC) was measured with a neutron probe (HYDROPROBE 503DR, CPN®, California), using the neutron scattering technique. A 50 mm Ø class 4 Polyvinyl chloride [IUPAC: Poly(chloroethanediyl)] neutron probe access tube was installed on the vine row of each experiment plot using a 50 mm custom built auger. Soil water content was measured at 300 mm, 600 mm, 900 mm and 1200 mm soil depths. Measurements were carried out every fourteen days from September until harvest and once per month following grape harvest. Five standard count readings were taken while the probe was standing on the neutron probe case, before and after the actual readings were recorded. Neutron probe count ratios were obtained by determining the ratio between the actual readings at each depth and the average of the ten standard count readings. The neutron probe count ratios were calibrated against the volumetric soil water content (Θ_v). The gravimetric soil water content (Θ_m) was determined by collecting soil samples over the 0-300 mm, 300-600 mm, 600-900 mm and 900-1200 mm depth increments using a Viehmeyer auger on the same days that neutron probe readings were taken. Soil samples were placed in metal cans of known mass and closed immediately. The samples were weighed on an electronic balance at the Irrigation laboratory at ARC Infruitec-Nietvoorbij. Thereafter, the cans were opened and placed in an extractor oven to dry at 105ºC for 24 hours (Hillel, 1980). After the samples were removed from the oven, the cans were closed and placed in a desiccator containing $CuSO_4$ crystals to cool down. Following this, samples were weighed and gravimetric soil water content was calculated by means of the following equations (Eq 4.1 to 4.3):

$$\Theta_m = (M_w - M_d) \div (M_d - M_c) \qquad \text{(Eq.4.1)}$$

where M_w is the mass of the moist soil, M_d is the oven-dry mass of the soil and M_c is the metal can mass. Volumetric soil water content was calculated as follows:

$$\Theta_v = \Theta_m \times \rho_b \qquad \text{(Eq.4.2)}$$

Where ρ_b is soil bulk density. The latter was taken as 1.5 kg/m^3 (P. Myburgh, personal communication).
Soil water content (SWC) for each layer was calculated as follows:

$$SWC = \Theta_v \times d \times 100 \qquad \text{(Eq. 4.3)}$$

where d is the depth of the soil layer (dm). The SWC for the layers were summed to obtain the water content in the soil profile.

4.2.4.4 Penetration resistance

The effect of the tillage and compost treatments on penetrometer soil strength (penetrometer resistance) was quantified by means of a hand held hydraulically driven penetrometer (Moolman & Van Huyssteen, 1989). Measurements were made on the work row at three locations in each treatment plot. Mean penetration resistance was recorded over 5 cm depth increments from the surface to the 75 cm soil layer. The SWC on the grapevine row was recorded at the time of measurement by means of neutron probe readings and soil samples were collected from the work row to determine gravimetric SWC.

4.2.4.5 Soil chemical and physical status

Prior to the application of the treatments, two profile pits were excavated in order to evaluate the rooting depth as well as root distribution in relation to the terrace. Soil samples were collected in July 2015 before the trial commenced in order to determine the baseline soil chemical status, soil texture and physical status. Samples were collected from the work row in each major plot using an auger (Fig. 4.7) Samples were taken at four depths (0-15 cm; 15-30 cm; 30-60 cm; 60-90 cm) at one position in each of the six major plots (Fig 4.7). All samples were quantified for $pH_{(KCl)}$, electrical conductivity of the saturated soil extract (EC_e), acidity, NH_4^+-N, P (Citric acid & Olsen), K^+, C (Walkley-Black), extractable cations (K^+_{Ex}, Ca^{2+}_{Ex}, Mg^{2+}_{Ex} & Na^+_{Ex}) and Cu^{2+}, Zn^{2+}, Mn^{2+}, B^{3+}, Fe^{2+}, texture, sand, silt, clay and stone by Elsenburg Agricultural Laboratory as per methods described in the Handbook of Standard Soil Testing Methods for Advisory Purpose published by Soil Society of South Africa (1990).

Figure 4.6. The locations where the initial soil samples were collected to obtain baseline values before the application of the treatments in September 2015.

In July 2017 soil samples were collected from three locations within each experiment plot at 0-15 cm, 15-30 cm, 30-60 cm and 60-90 cm depths. Soil $pH_{(KCl)}$, EC_e, NH_4^+-N , P, K^+, Na^+_{Ex}, K^+_{Ex}, Ca^{2+}_{Ex}, Mg^{2+}_{Ex}, Cu^{2+}, Zn^{2+}, Mn^{2+}, Fe^{2+}& B^{3+} and organic C were determined at Elsenburg Agricultural Laboratory as per methods described in the Handbook of Standard Soil Testing Methods for Advisory Purpose published by Soil Society of South Africa (1990).

The extractable sodium percentage (ESP') was calculated as follows:

$$ESP' = (Na^+ \div S) \times 100 \qquad \text{(Eq. 4.4)}$$

where Na^+ is the extractable sodium ($cmol^{(+)}/kg$) and S is the S-value ($cmol^{(+)}/kg$), *i.e.* the sum of the Ca^{2+}, Mg^{2+}, K^{2+} and Na^+. The designation ESP' is used so as not to confuse extractable sodium percentage, which includes both adsorbed Na^+ and Na^+ in solution, with ESP.

4.2.5 Statistical analysis

The data were subjected to an analysis of variance. Least significant difference (LSD) values were calculated to facilitate comparison between treatment means. Means which differed at $p \leq 0.05$ were considered to be significantly different. Statgraphics® was used to fit linear regression models.

4.3 Results

4.3.1 Atmospheric conditions

Please refer to Section 3.3.1 in Chapter 3 for a detailed description of the atmospheric conditions.

4.3.2 Water infiltration

The water infiltration rate ranged from 432 mm/h to 744 mm/h (Fig. 4.7). Water infiltration rate was higher in the soil of the compost-amended treatments (FP+comp & RP+comp) relative to the control (Fig.4.7). Since the FP+comp treatment was applied to the middle of the work row, the organic material was concentrated in this area. The infiltration rate of the root pruning treatment without compost (RP) did not differ from the control. High infiltration rates have been related to the presence and location of SOC, reduced bulk density and improved aggregate stability (Franzluebbers 2002). In a study in which several organic amendments (poultry manure, sewage sludge, barley straw & alfalfa) were evaluated, water infiltration rates responded positively to stimulated microbial activity and increased aggregate stability (Martens & Frankenberger, 1992). Additional organic amendments in the aforementioned trial resulted in decreased bulk density and increased cumulative infiltration rates. In the current trial, the rate of water infiltration into the soil was measured in the middle of the work row, which accounts for the high infiltration rate observed in the furrow plough treatment where the organic material was concentrated. The root pruning with compost incorporation was applied to the entire area between the tractor wheels, resulting in a greater distribution of organic material to a depth of *c*. 45 cm. High infiltration rates are expected to increase the amount of water entering the soil and decrease water loss due to runoff.

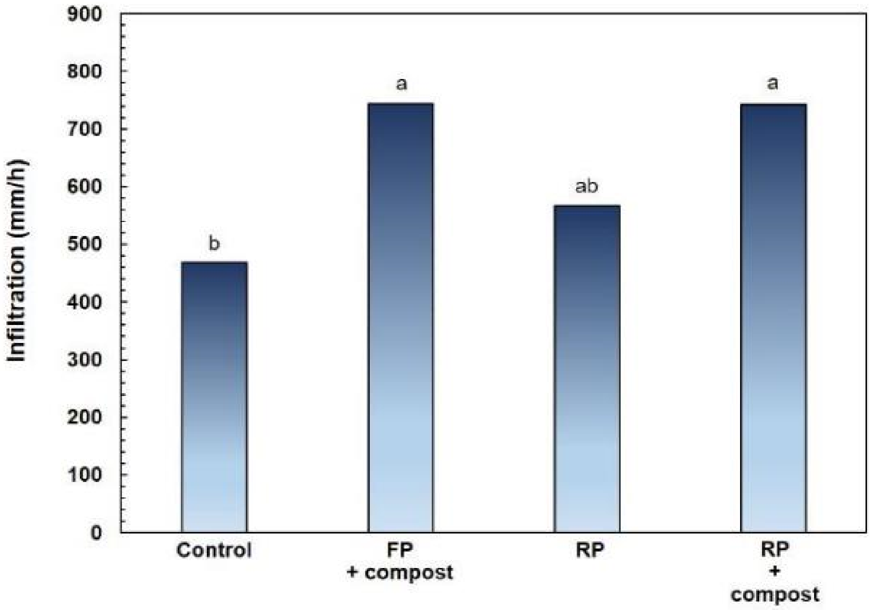

Figure 4.7. The effect of tillage and compost incorporation on the rate of water infiltration into soil in the work row.

4.3.3 Soil water content

Seasonal soil water depletion in the 0-120 cm, as well as the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm depth increments, are presented in Figures 4.8 and 4.9 respectively, for the 2015/16 season. Figures 4.10 and 14.11A-D represent SWC depletion during the 2016/17 season in the 0-120 cm, and the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm depth increments, respectively. At the beginning of the 2015/16 growing season, before bud break, the total SWC on the grapevine row was approximately 248 mm for all treatments (Fig. 4.8). Thereafter the SWC gradually declined until pea size berries when a rainfall event occurred, depicted by the small peak in the graph. The SWC subsequently declined further to *c.* 195 mm. Rainfall between early March and beginning of June was limited therefore resulting in only a gradual increase in SWC to *c.* 215 mm in the 120 cm soil depth layer. Winter rainfall from June to August 2016 (320 mm) wet the soil to a SWC level of *c.* 265 mm. In the 0-30 cm soil layer, the SWC was *c.* 52 mm at the start of the 2015/16 season (Fig. 4.9A). The SWC in this layer gradually declined to *c*. 45 mm before a major rainfall event in early December, depicted by the small peak in the graph (Fig. 4.9A) which increased the SWC to 53 mm. The 0-30 cm layer was driest in early March 2016 (41 mm) and wettest in July 2016 (65 mm). Changes in SWC followed a similar pattern in the 30-60 cm and 60-90 cm layers but the 30-60 cm layer was slightly drier than the 60-90 cm layer throughout the measurement period (Fig 4.9B-D). The SWC fluctuated less in the 90-120 cm layer, compared to the other layers. Following the rainfall from June to August, the SWC reached 73 mm in the 90-120 cm soil layer.

At the start of the 2016/17 season, total SWC ranged from 261 mm to 276 mm to a depth of 120 cm (Fig. 4.10), which was slightly higher than in 2015/16. The SWC of all treatments gradually declined to 214 mm at pea size berries and 193 mm at véraison. Winter rainfall, which began in June, increased the SWC to 245 mm by early August 2017. Greater fluctuations in SWC in the 0-30 cm layer were measured, but were comparable between treatments (Fig. 4.11A). A rainfall event of 13 mm in mid-January resulted in a slight increase in SWC in the 0-30 cm layer but had no effect on the deeper soil layers. Winter rainfall in June resulted in a rapid increase in SWC in the 0-30 cm layer and gradual increases in SWC in the 30-60 cm, 60-90 cm and 90-120 cm layers (Fig. 4.11B-D). The soils of all treatments followed a similar pattern of soil water depletion and there were no differences in SWC between treatments in each layer as well as throughout the entire soil profile during both measurement periods. The various tillage and compost treatments therefore had no effect on the SWC on the grapevine row compared to the control. Since infiltration was highest in the compost-amended treatments (FP+comp and RP+Comp), an increase in SWC on the work row would be expected. This would suggest that there was limited lateral movement of water from the work row to the grapevine row. It should be noted that measuring SWC in the work row was beyond the scope of the study.

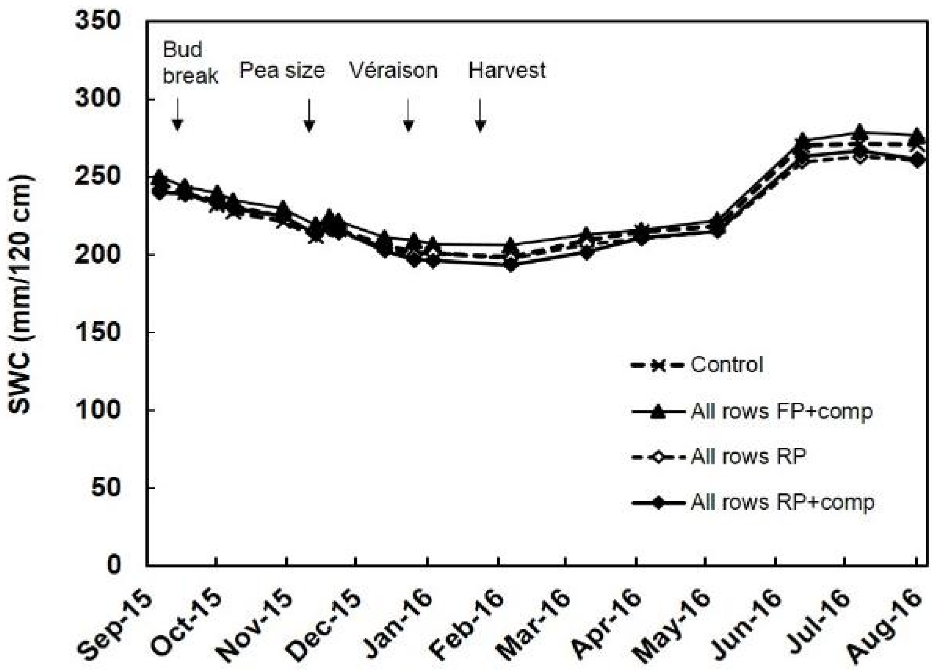

Figure 4.8. Effect of tillage and compost incorporation on the soil water content (SWC) to a depth of 120 cm on the grapevine row during the 2015/16 season.

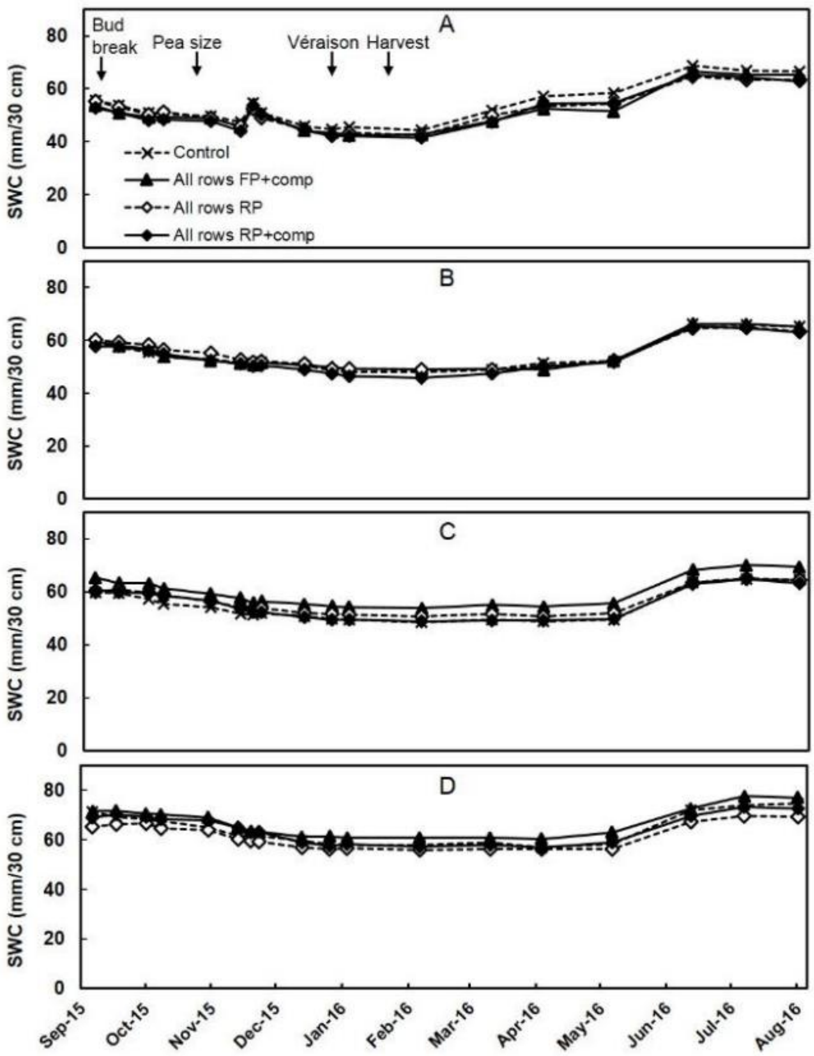

Figure 4.9. Effect of furrow plough (FP), root pruning (RP) and incorporation of compost (comp) on temporal variation in soil water content (SWC) of selected treatments in the (A) 0-30 cm, (B) 30-60 cm, (C) 60-90 cm and (D) 90-120 cm soil layers on the grapevine row during the 2015/16 season.

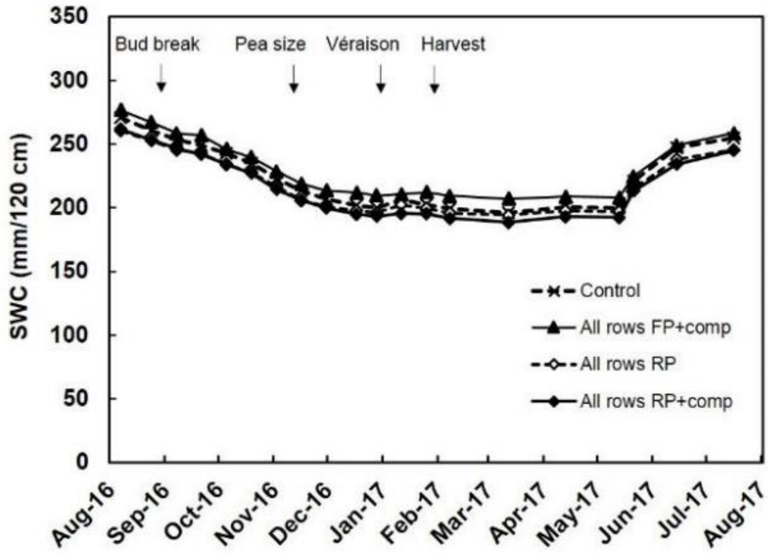

Figure 4.10. Effect of tillage and compost incorporation on the soil water content (SWC) to a depth of 120 cm on the grapevine row during the 2016/17 season.

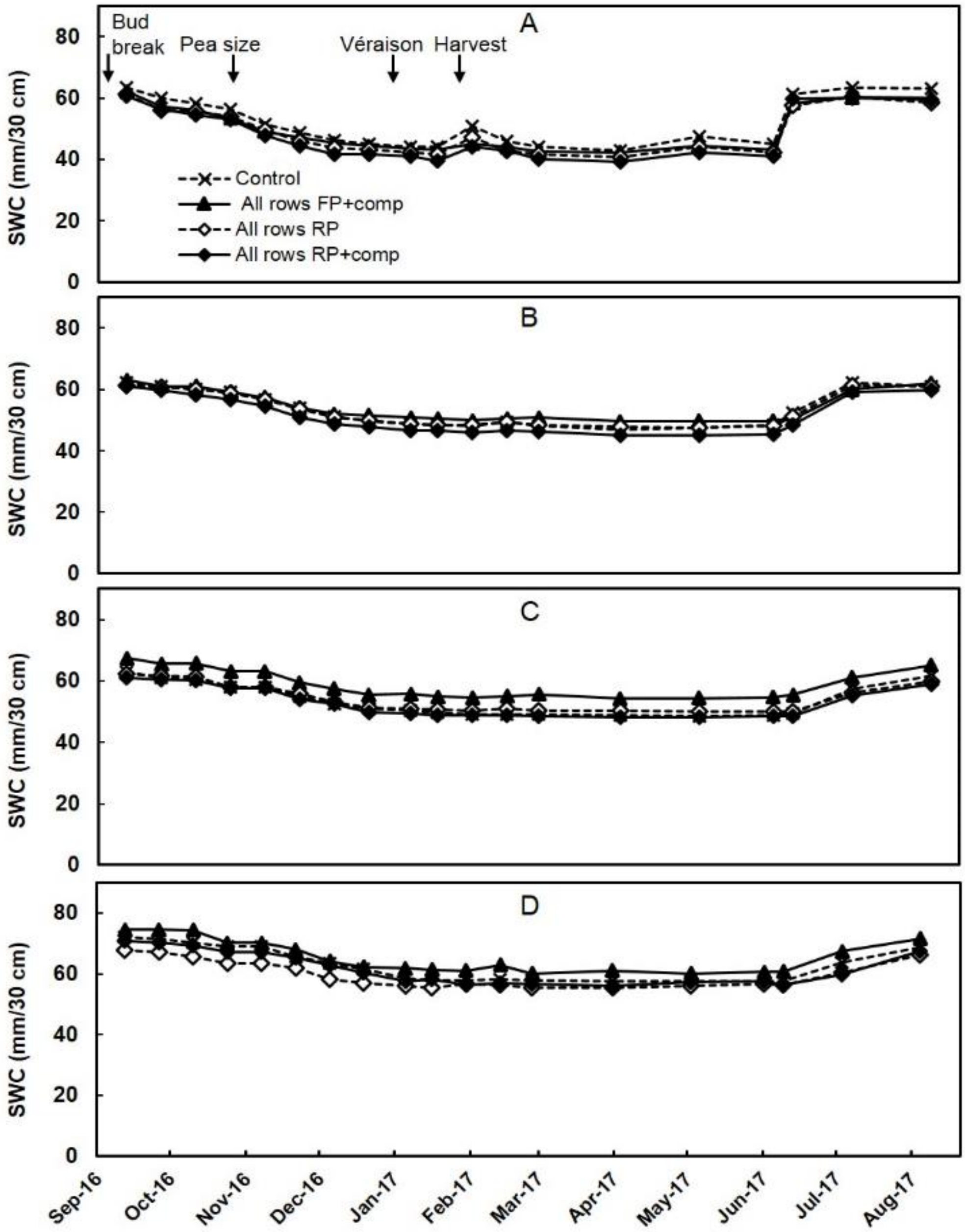

Figure 4.11. Effect of furrow plough (FP), root pruning (RP) and incorporation of compost (comp) on temporal variation in soil water content (SWC) of selected treatments in the (A) 0-30 cm, (B) 30-60 cm, (C) 60-90 cm and (D) 90-120 cm soil layers on the grapevine row during the 2016/17 season.

4.3.4 Penetration resistance

Soil water content in the work rows was fairly homogenous when the penetration resistance was measured, except for slightly wetter conditions near the surface in the case FP+comp (Fig. 4.12). It is interesting to note the lack of differences in SWC on the grapevine row at the time the penetrometer readings were recorded (Fig. 4.13). The treatments had an effect on penetration resistance up to a depth of 45 cm in comparison to the control (Fig. 4.14). Below this depth, penetration resistance among the treatments was comparable to 80 cm depth. The soil of the control had the highest penetration resistance to a depth of 20 cm and exceeded the 2000 kPa level where root growth is inhibited (Van Huyssteen, 1989) at a depth of 12 cm. The soil of FP+comp had the lowest penetration resistance until 15 cm below the soil surface, which indicated that the effective depth of this action was *c.* 15 cm. In the 0-30 cm soil layer on the work row, the SWC of FP+comp was slightly higher compared to the control and other treatments (Fig. 4.14). The initial low penetration resistance measured in the soil of FP+comp can be explained by the higher SWC and concentration of organic matter in this layer. Below 20 cm, the penetration resistance of the FP+comp and the control soils were comparable. From 15 cm to 45 cm, RP and RP+comp demonstrated the lowest penetration resistance (1333-1465 kPa) compared to the control and FP+comp. The lack of differences between the treatments below 45 cm implies that the root pruning action was generally effective to a depth of *c.* 45 cm to 50 cm. The above results indicate that FP+comp was effective in providing more favourable soil physical conditions for root development in the work row in the 0-15 cm soil layer, whereas RP and RP+comp decreased soil strength to a depth of 45 cm. It could be inferred that in the case of RP+comp, the root exploitable soil volume is increased in addition the soil water storage capacity due to the compost. In a soil preparation study, performance of Colombar grapevines on Hutton/Clovelly soils was directly related to root development, which was a function of the volume of soil loosened (Saayman, 1982). The results of a related study concluded that organic matter (OM) incorporation during soil preparation had no effect on soil water content and grapevine performance (Saayman & Van Huyssteen, 1980). In the aforementioned study, OM was applied at a rate of 40 t/ha (80 m^3) to a depth of 120 cm. The 57 t/ha OM which was applied in the current trial was deposited in a furrow (FP+comp) measuring 15-20 cm in depth whereas for RP+comp, the same amount of OM was applied to the entire work row to a depth of 45-50 cm. All tillage actions increased the root colonisable soil volume but the greatest increase was observed where OM was concentrated. Increased cover crop performance in FP+comp may have also contributed to this development by positively affecting infiltration. The effect of cover crop in reducing runoff and erosion has been demonstrated (Louw & Bennie, 1991).

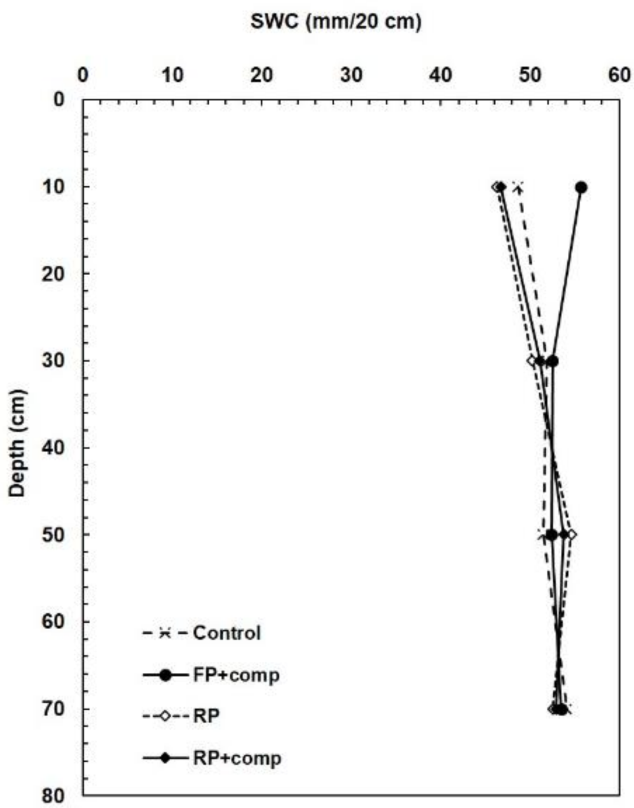

Figure 4.12. Soil water content (SWC) on the work row when penetrometer readings were carried out.

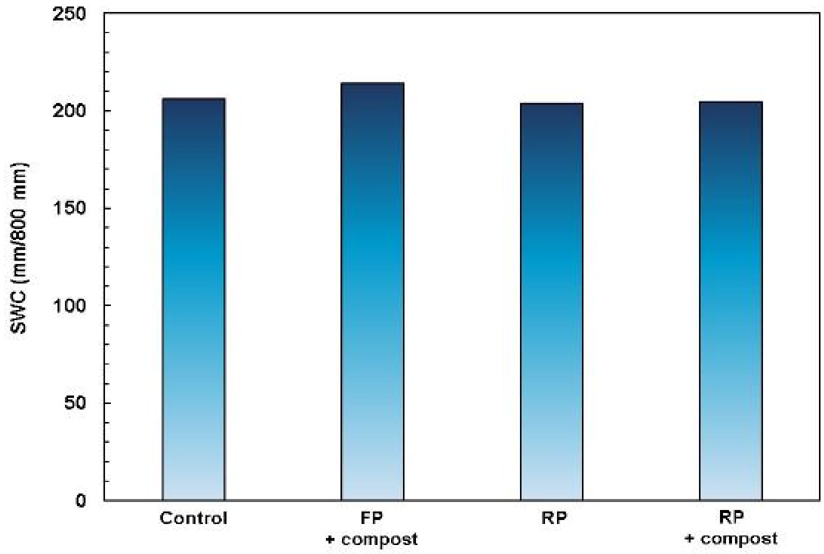

Figure 4.13. Soil water content (SWC) on the grapevine row when penetrometer readings were carried out.

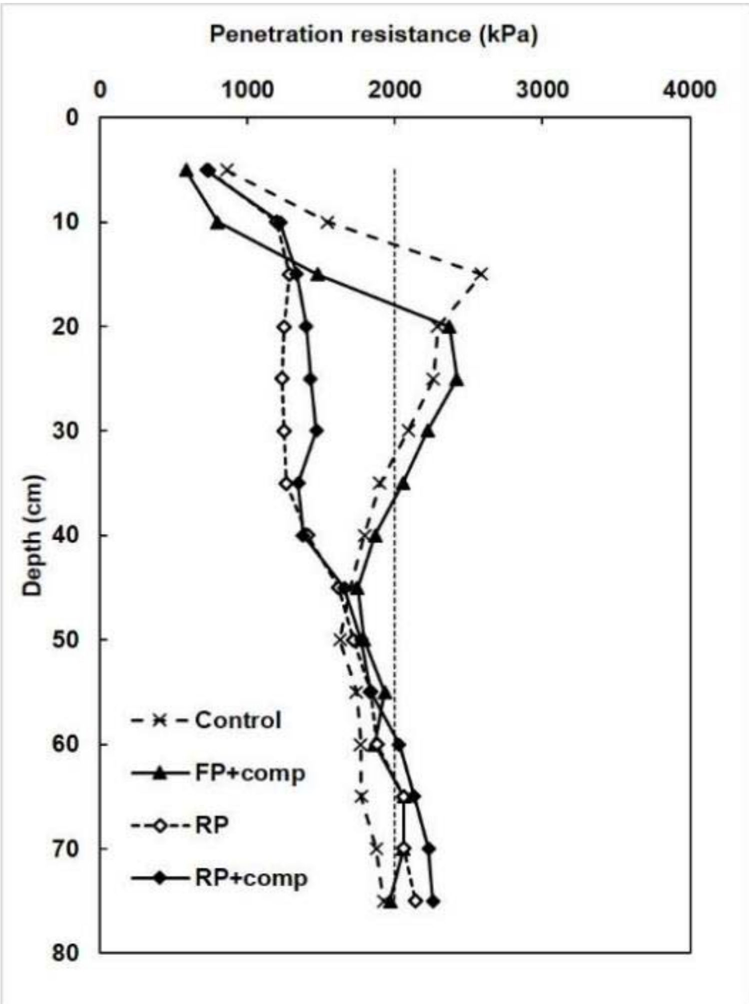

Figure 4.14. The effect of the furrow plough, root pruning actions with and without compost incorporation, on soil strength in the work row in September 2016. Dashed line indicates the penetration resistance threshold at which root growth is inhibited as reported by Van Huyssteen (1989).

4.3.5 Soil chemical status

4.3.5.1 Initial soil chemical status

The initial soil $pH_{(KCl)}$ was below the recommended norm of 5.5, and mean phosphorus (P) and potassium (K) levels were below the recommended norms for grapevine growth (Conradie, 1994), therefore the baseline soil properties indicated that chemical constraints may have contributed to the overall poor growth (Table 4.4 & 4.5). Baseline values for the trace elements indicated that no major deficiencies occurred (data not shown). Since the aim of the study was to determine to what extent the tillage and compost treatments affected performance in the vineyard, no adjustments were made to the soils before the treatments were applied.

Table 4.4. The mean particle size distribution and soil textural class of the soil where the field trial was carried out.

Depth (cm)	**Clay** (%)	**Silt** (%)	**Fine sand (%)**	**Medium sand (%)**	**Coarse sand (%)**	**Texture**
0-15	22.3	15.3	26.2	22.7	13.5	Coarse sandy clay loam
15-30	26	14.7	17.2	26.5	15.7	
30-60	28.8	14	19.4	23.6	14.2	
60-90	30.3	3.7	15.5	25.5	15	
Block mean	26.3	14.5	20	24.6	14.6	

Table 4.5. The mean soil chemical status in 2015 of the coarse sandy loam soil in which the field trial was carried out.

Depth	**pH**	**EC_e**	**N-NH_4^+**	**P Citric**	**K**	**Extractable Cations**				**C**
(cm)	**(KCl)**	**(dS/m)**	**(%)**	**(mg/kg)**	**(mg/kg)**	**Ca^{2+}_{Ex} ($cmol^{(+)}$/kg)**	**Mg^{2+}_{Ex} ($cmol^{(+)}$/kg)**	**K^{+}_{Ex} ($cmol^{(+)}$/kg)**	**Na^{+}_{Ex} ($cmol^{(+)}$/kg)**	**(%)**
0-15	5.32	1.27	0.06	12.33	72.33	2.35	0.61	0.19	0.09	0.67
15-30	5.30	1.06	0.05	7.50	45.67	2.07	0.40	0.12	0.08	0.61
30-60	5.35	1.04	0.04	5.17	35.50	2.01	0.31	0.09	0.09	0.40
60-90	5.32	0.89	0.03	2.50	26.00	1.69	0.31	0.07	0.09	0.38
Mean	5.32	1.04	0.04	6.88	44.88	2.03	0.41	0.12	0.09	0.51

4.3.5.2 Electrical conductivity and pH

The baseline value for EC_e to a depth of 90 cm was 1.04 dS/m, which indicated that there were no salinity problems before the tillage and compost treatments were applied. Clear differences in mean soil EC_e were observed between treatments, with higher EC_e values observed in the soils of the FP+comp and RP+comp treatments compared to the control and RP treatments (Fig. 4.15A). As expected, soil EC_e of the control was similar to levels measured before the trial commenced. The soil of FP+comp had the highest EC_e and was also higher than that of RP+comp. The soil EC_e, which gives an indication of the extent to which salts may affect plant development, appeared to increase where compost had been applied, and more so where it was concentrated. The furrow plough with compost and root pruning with compost increased the soil EC_e to a depth of 30 cm (Fig 4.16). In the 0-15 cm soil layer, the soil EC_e of RP+comp approached the threshold for restricted grapevine yield, *i.e* 1.8 dS/m (Abrol *et al*., 1988) and exceeded the threshold of 1.5 dS/m recommended for vineyards in the Breede River Valley (Myburgh & Howell, 2014). The soil EC_e of FP+comp was so high it exceeded both thresholds. Salts in the shallow soil layers would be expected to leach to some extent to the deeper soil layers over time and since the compost application is a once-off application, salinity is not expected to have a negative long-term effect on grapevine growth and yield.

Almost two years after the tillage and compost treatments were applied, clear trends in soil $pH_{(KCl)}$ were observed in response to the tillage and compost treatments. The baseline value for soil $pH_{(KCl)}$ was 5.3 for the 0-90 cm soil depth, which is below the recommended norm of 5 to 7.5 recommended for grapevine growth (Saayman, 1981) (Fig.4.16B). The mean soil $pH_{(KCl)}$ of FP+comp and RP+comp was 5.96 and 5.72, respectively, in the 0-90 cm soil depth. The mean soil $pH_{(KCl)}$ in the 0-90 cm soil depth of the control and RP was 5.28 and 5.45, respectively. The incorporation of compost by the furrow plough and by root pruning increased soil pH, but only to a depth of 15 cm (Fig. 4.17). Between 15 cm and 30 cm, the $pH_{(KCl)}$ of the soil where compost had been incorporated, tended to be higher than that of the control and RP soil but below 30 cm, there were no major differences in the soil $pH_{(KCl)}$ between treatments. The soil pH increase was probably a function of organic compounds introduced in the compost, through mechanisms illustrated in Figure 2.3 of Section 2.3.3.2 in Chapter 2. (Rukshana *et al*., 2011). The dissociation of H^+ from organic acids results in the formation of organic anions, and the decarboxylation thereof increases soil pH. If cations are present in the form of organic salts, decarboxylation may also increase soil pH. Similar findings in terms of increased pH were observed where diluted winery waste water was applied to soils (Mulidzi, 2016). Soil pH also increased in the 0-15 cm soil layer where municipal compost and manure based compost were applied (Eghball, 2002). (A soil $pH_{(KCl)}$ below 5.5 indicates high soil acidity, which can indirectly create Al^{3+} toxicity and restrict root growth (Kotze, 1973; Van Schoor *et al.*, 2000). Soil pH has an effect on the availability of nutrients for root uptake and on soil biological activity.

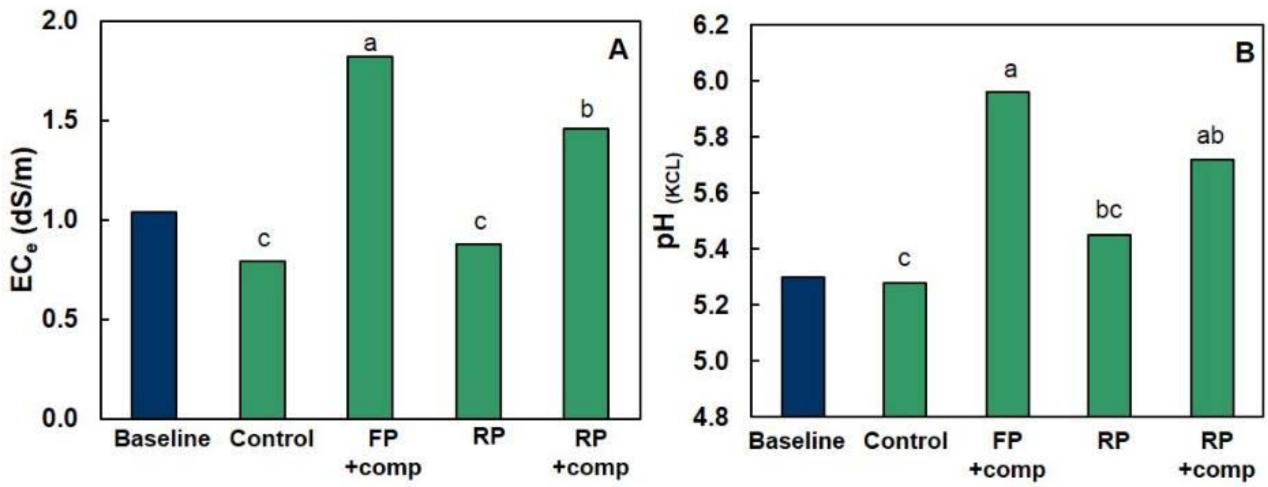

Figure 4.15. The affect of tillage and compost on the (A) electrical conductivity of the saturated extract (EC_e) and (B) $pH_{(KCl)}$ of the soil (0-90 cm depth) in the work row compared to the control and the baseline value. For each variable, columns designated by the same letter do not differ significantly ($p \leq 0.05$).

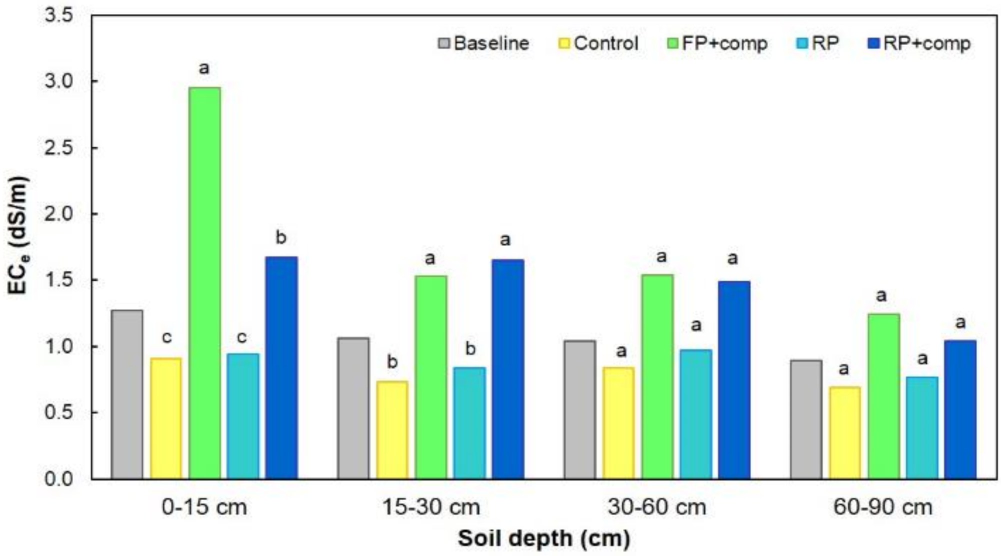

Figure 4.16. Soil electrical conductivity of the saturated extract (EC_e) two years after tillage and compost was applied compared to the baseline soil EC_e. For each depth, columns designated by the same letter do not differ significantly ($p \leq 0.05$).

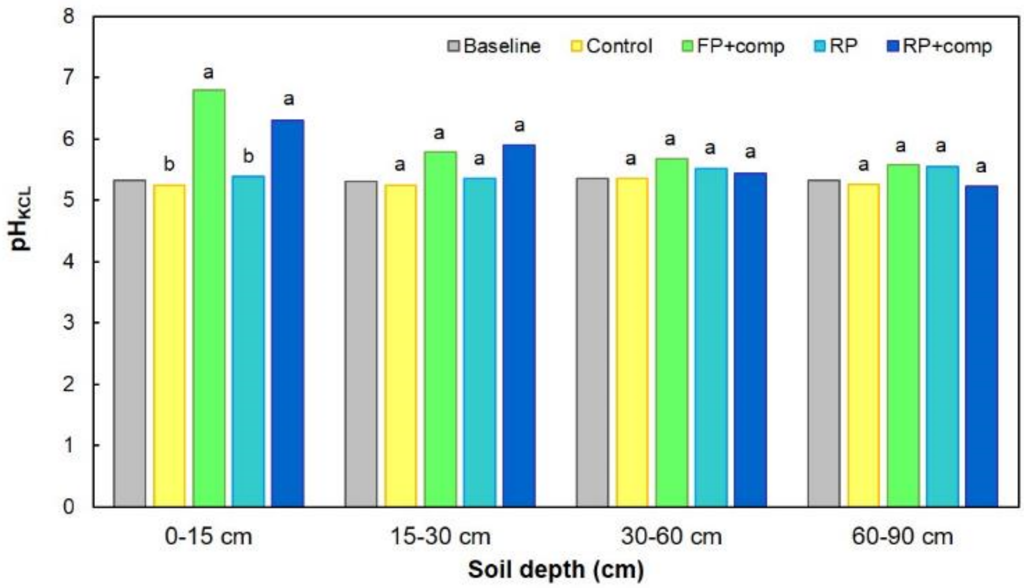

Figure 4.17. The effect of tillage and compost on soil $pH_{(KCl)}$ in the 0-15 cm, 15-30 cm, 30-60 cm and 60-90 cm soil layers in the work row, compared to the baseline soil pH_{KCL}. For each depth, columns designated by the same letter do not differ significantly ($p \leq 0.05$).

4.3.5.3 Carbon, Nitrogen, Phosphorus and Potassium

The baseline organic C content was *c.* 0.67% (Fig. 4.18A). Two seasons after treatment application, the mean C in the 0-90 cm soil layer was substantially higher where compost had been incorporated using the furrow plough compared to all other treatments. Where compost was incorporated by root pruning (RP+comp), the mean C content to a depth of 90 cm tended to be higher than the control but was lower than FP+comp. This may have been a result of the wider distribution of compost in the RP+comp treatment compared to the FP+comp treatment, where the compost was concentrated in the 0-15 cm layer. In the 0-15 cm soil layer, FP+comp and RP+comp increased the C compared to the control and RP (Fig. 4.19). In the 15-30 cm and 30-60 cm soil layers, only RP+comp increased the C compared to the control. Below 60 cm, tillage and compost had no effect on soil C. Therefore, incorporating compost by means of the furrow plough substantially increased C to a depth of 15 cm, whereas incorporating compost during root pruning tended to increase C less substantially but to a greater depth *i.e.* 60 cm. Organic C does not serve as a direct nutrient source for grapevines but has an effect on various soil properties and provides an indication of the N availability in the soil. Heavier soils with a clay content greater than 6 % and a C content equal to, or greater than 0.9% may provide sufficient N to meet the nutrient requirements of grapevines *i.e.* no fertilisation is required (Conradie, 1994). The clay content and baseline C content values for this soil were 26.3% and 0.67%, respectively. Therefore, N fertilisation would seldom be necessary, but an increased C may increase the amount of N available to the plants.

The mean soil $NH4^+$-N in the 0-90 cm soil layer was higher in the soils of the FP+comp treatment, compared to the control and other treatments (Fig. 4.18B). In vineyards where the clay content is above 6% and the OM exceeds 1.5%, soils may meet the N-demand of grapevines without fertilizer addition (Conradie, 1994). However, factors affecting the rate of mineralisation and the quantity of mineralisable N also play a role, such as soil water content. High N availability has been associated with deep soil loosening due to N mineralisation below 60 cm during soil preparation (Conradie *et al*., 1996). The N requirement of grapevines peaks before bloom until véraison, and again from harvest until leaf fall (Conradie, 1980) but the critical period for N application is during the post-harvest when N reserves are affected (Conradie, 1986). Therefore, the timing of N fertilisation is important for efficient application. In the case of this study, compost and tillage had no effect on NH_4^+-N below 15 cm (data not shown). However, in the 0-15 cm soil layer, NH_4^+-N increased where compost was incorporated with the furrow plough (Fig. 4.20). It would seem that deep tillage had no effect mineralisation of N in the deeper soil layers which suggests that N-resources were perhaps near depletion below 60 cm. The increased NH_4^+-N in the 0-15 cm soil layer is likely due to the high N content in the compost.

The soil contained an average of 6.88 mg/kg phosphorus (P_{citric}) to a depth of 90 cm in the work row before the various tillage and compost treatments were applied (Fig. 4.18C). The 0-15 cm, 15-30 cm and 30-60 cm soil layers contained 12.3 mg/kg, 7.5 mg/kg and 5.7 mg/kg P_{Citric} respectively. This is the equivalent of *c*. 22 mg/kg Bray-II P for soils with a pH of 5.0-5.9 (Conradie, 1994). This value is lower than the norm of 30 mg/kg P based on Bray II extraction for soils with clay > 15 % and pH of 5.5, proposed by Conradie (1994). The mean soil P_{citric} content to a depth of 90 cm of FP+comp was considerably higher than in the control and all other treatments. In the 0-15 cm soil layer, the same relationship was found (Fig. 4.21). In the 15-30 cm soil layer, only RP+comp increased the soil P_{citric} compared to the control. In the 30-90 cm soil layer, the FP+comp treatment increased soil P_{citric}, compared to the control whereas the RP and RP+comp treatments had no effect on soil P_{citric} below 30 cm. The increase in soil P_{citric} in response to the furrow plough with compost treatment resulted in a P_{citric} content in the 0-15 cm soil layer which is higher than the minimum requirement for vineyards (Conradie, 1994). Phosphorous availability is strongly dependent on soil pH (Devau *et al*., 2009). Where soil pH is within the 5-6.5 range, soil P has been shown to increase with soil pH on shale-derived soils in Stellenbosch (Mulidzi, 2016).

The baseline soil K^+ in the 0-90 cm layer was 44.9 mg/kg which is lower than the recommended norm of 70-80 mg/kg for red and yellow, medium textured soils (Conradie, 1994). The mean soil K^+ of FP+comp was substantially higher in the 0-90 cm layer than all the other treatments and the control (Fig. 4.18D). The mean soil K^+ of RP+comp was also higher than the K^+ in the control and RP treatments. Root pruning without compost had no effect on the K^+ of the soil compared to the baseline K^+ levels. In the 0-15 cm soil layer, FP+comp and RP+comp increased soil K^+ compared to the control and RP (Fig. 4.22). In the 15-30 cm soil layer, only FP+comp increased the soil K^+ compared to the control. However, in the 30-60 cm soil layer, only RP+comp increased soil K^+ compared to the control. Below 60 cm, tillage and compost had no effect on K^+ content. In a previous study, it was reported that manure-based compost resulted in the highest P and K^+ surplus in soils, compared to raw dairy manure and conventional mineral fertilizer (Reider *et al.*, 2000). Excessively high soil K^+ may lead to an increase in the K^+ uptake by grapevines. The negative consequences of high K^+ levels in grapevine berries include high juice pH, increased malate concentrations and reduced wine colour (Ruhl, 1989; Mpelasoka *et al*., 2003; Kodur, 2011). Since the soil K^+ levels of most of the treatments were well below the norm recommended by Conradie, negative effects on juice pH and wine were not to be expected under the prevailing conditions.

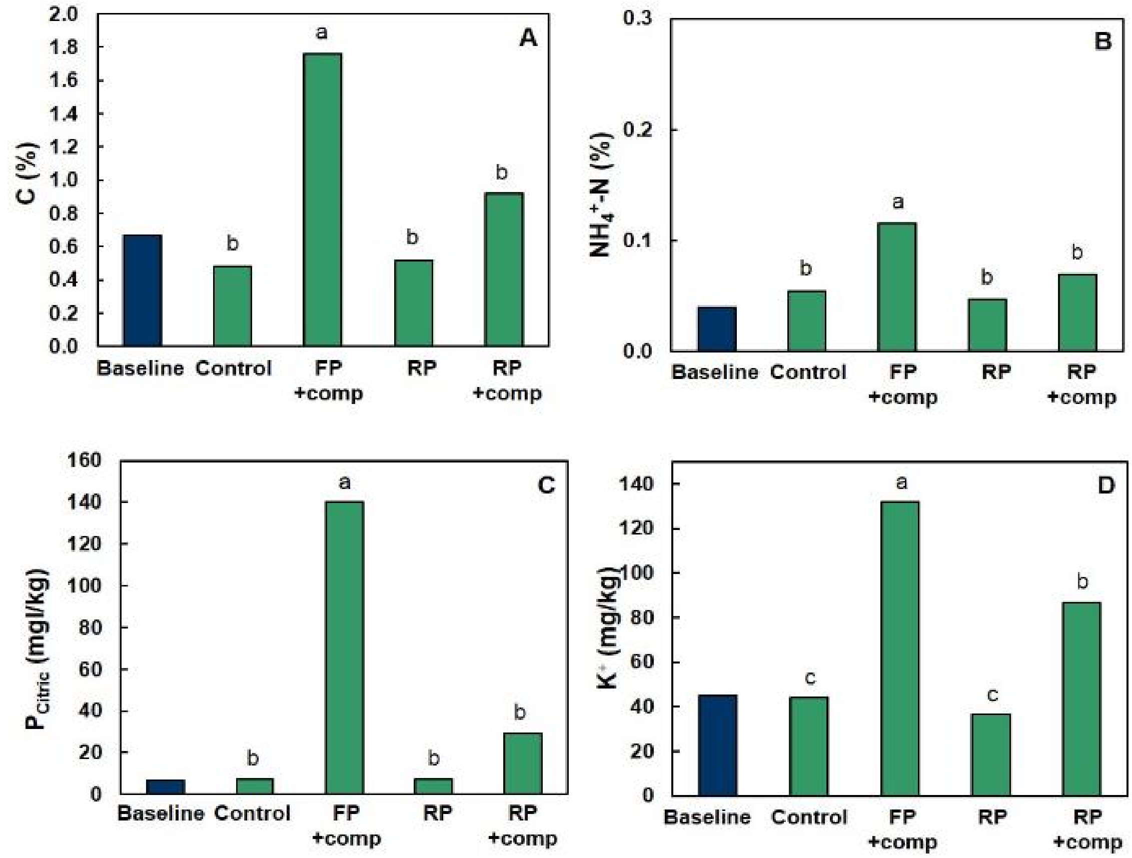

Figure 4.18. The effect of tillage and compost on (A) the organic carbon (C), (B) ammonium nitrogen (NH_4^+), (C) phosphorus (P) and (D) potassium (K^+) contents in the 0-90 cm soil depth in the work row compared to the control and the baseline value. For each variable, columns designated by the same letter do not differ significantly ($p \leq 0.05$).

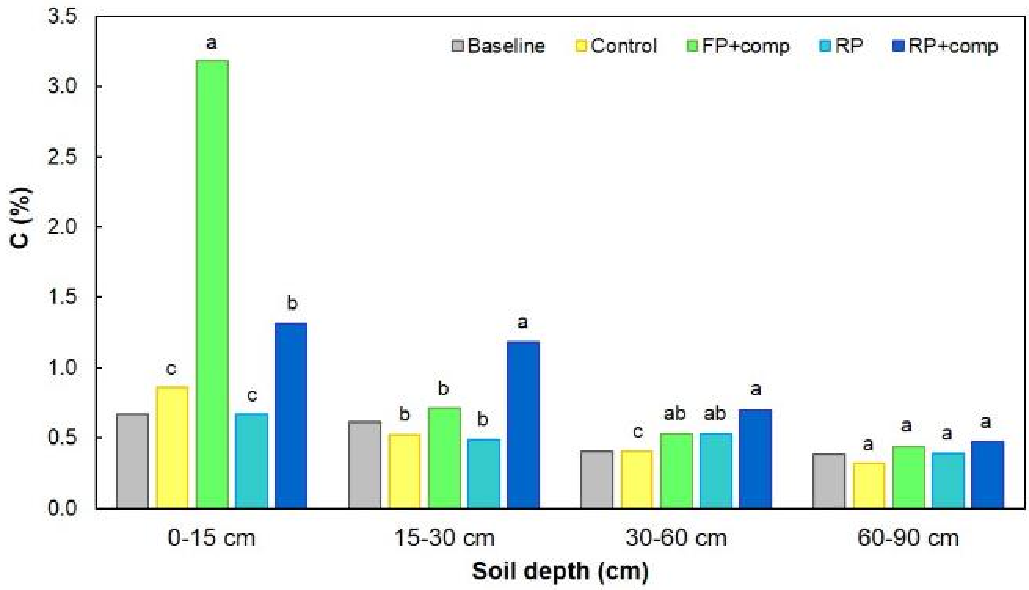

Figure 4.19. The effect of tillage and compost on the organic carbon (C) content in the 0-15 cm, 15-30 cm, 30-60 cm and 60-90 cm soil layers in the work row. For each depth, columns designated by the same letter do not differ significantly ($p \leq 0.05$).

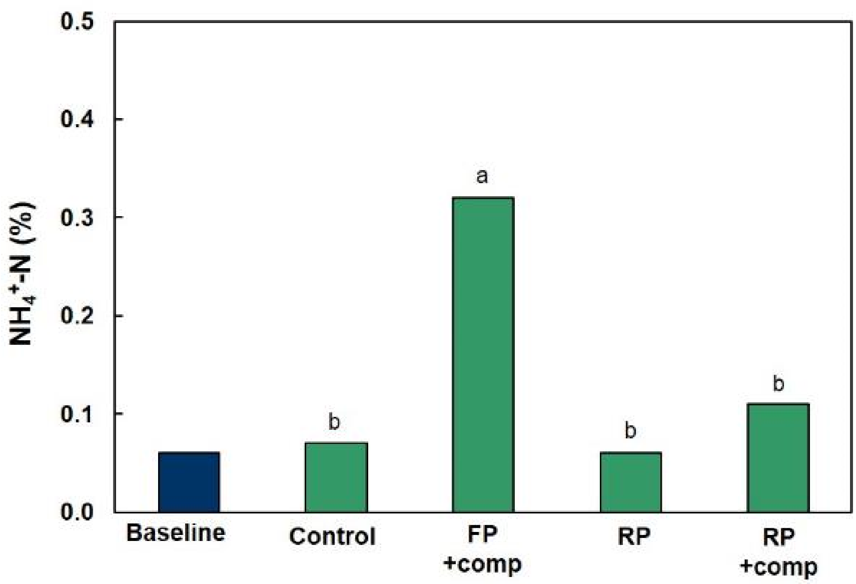

Figure 4.20. The effect of tillage and compost on the ammonium (NH_4^+) content in the 0-15 cm soil layer in the work row. Columns designated by the same letter do not differ significantly ($p \leq 0.05$).

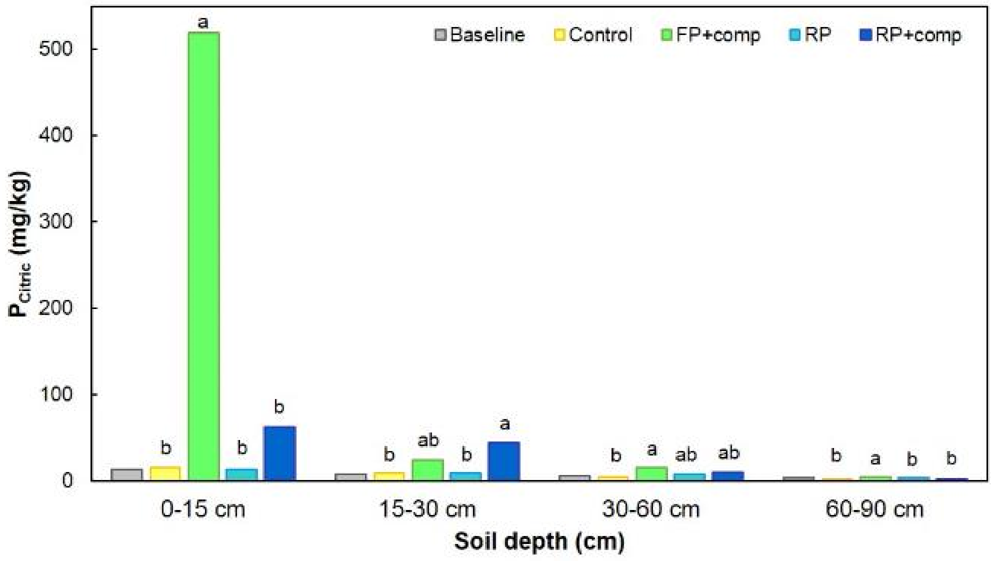

Figure 4.21. The effect of tillage and compost on the phosphorus (P_{Citric}) content in the 0-15 cm, 15-30 cm, 30-60 cm and 60-90 cm soil layers in the work row. For each depth, columns designated by the same letter do not differ significantly ($p \leq 0.05$).

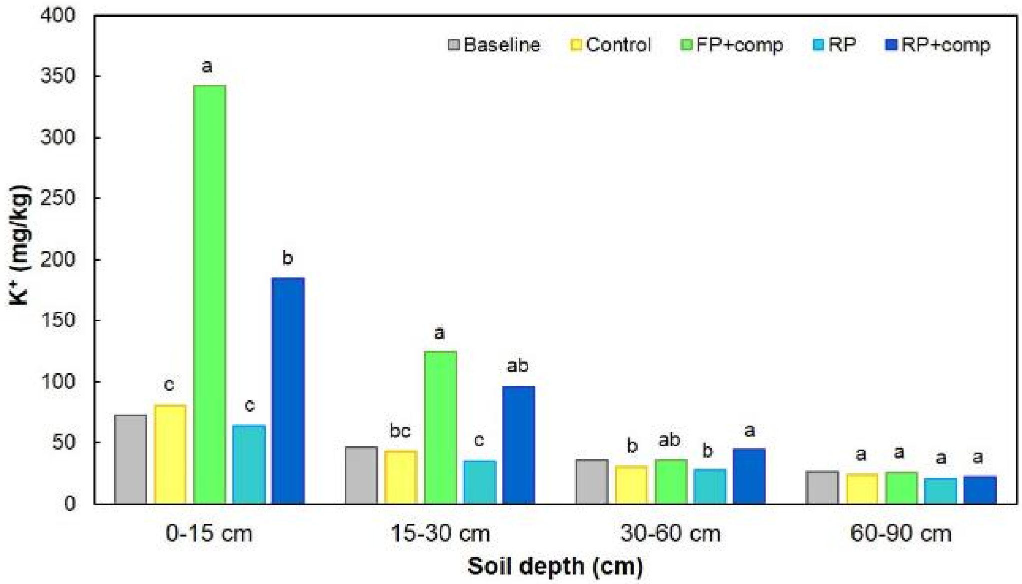

Figure 4.22. The effect of tillage and compost on the potassium (K^+) content in the 0-15 cm, 15-30 cm, 30-60 cm and 60-90 cm soil layers in the work row. For each depth, columns designated by the same letter do not differ significantly ($p \leq 0.05$).

4.3.5.4 Extractable cations

The mean extractable Ca^{2+}_{Ex}, Mg^{2+}_{Ex}, K^+_{Ex} and Na^+_{Ex} levels to a depth of 90 cm followed a similar trend (Fig. 4.23A-D). The soil of FP+comp had the highest Ca^{2+}_{Ex} content of 12.12 cmol$^{(+)}$/kg compared to the 2.60 cmol$^{(+)}$/kg of the control and the 2.03 cmol$^{(+)}$/kg of the baseline measurement (Fig. 4.23A). The mean Ca^{2+}_{Ex} content of the soils of RP and RP+comp did not differ from the control. Higher extractable calcium levels in the soil of the FP+comp treatment could be explained by the high calcium content in the compost, compared to other cations. The baseline Mg^{2+}_{Ex} content was 0.41 cmol$^{(+)}$/kg. The response of soil Mg^{2+}_{Ex} to the tillage and compost treatments followed the same pattern as soil Ca^{2+}_{Ex}, with the highest amount of Mg^{2+}_{Ex} observed in the soil of FP+comp (Fig. 4.23B).

The mean soil Mg^{2+}_{Ex} of RP and RP+comp did not differ from the control. The baseline soil K^{+}_{Ex} was c. 0.12 $cmol^{(+)}$/kg (Fig. 4.23C). The soil K^{+}_{Ex} of FP+comp was higher than that of the control and RP but did not differ from RP+comp. Root pruning with compost only tended to increase mean extractable potassium, and root pruning without compost had no effect on mean extractable potassium. Potassium fertilisation may induce positive growth responses where K^+ deficiency is a concern, but excess K^+ has no effect on canopy size where levels of K^+ in the soil are adequate (Morris & Cawthon, 1982). In fact, excess K^+ fertilisation has been found to negatively affect petiole Ca^{2+} and Mg^{2+}, increase juice pH and decrease acidity (Morris *et al*., 1980).

The mean soil Na^{+}_{Ex} of FP+comp was higher than the control and the other treatments (Fig. 4.23D). The soil Na^{+}_{Ex} of RP+comp was higher than the control but did not differ from RP and soil Na^{+}_{Ex} of the RP treatment did not differ from the control. Therefore, where compost was incorporated, the Na^{+}_{Ex} of the soil increased, particularly where it was concentrated. While the levels of all of the above mentioned extractable cations increased in response to compost, only the Na^+ levels may be cause for concern due to the risk of sodicity. Since the Ca:Mg ratio of the soils where compost was applied ranged from 5:1 to 8:1, and the pH increased towards the optimum in these soils, the increase in Ca^{2+} and Mg^{2+} was not considered detrimental to grapevine growth (Conradie *et al*., 1994). However, excessive Na^+ can reduce grapevine vegetative growth and yield (Myburgh & Howell, 2014). The tillage and compost treatments had no effect on the mean ESP' to a depth of 90 cm (Fig. 4.24). In fact, in the 0-15 cm soil layer, the ESP' decreased where compost was incorporated by means of the furrow plough and root pruning (Fig. 4.25). The high Ca^{2+} content in the compost (Refer to Table 4.3) appeared to have had a suppressive effect on the ESP'. The ESP' in the deeper soil layers did not differ between treatments (data not shown). While the compost increased the Na^+ content, in relation to the other cations the Na^+ levels were not actually high and were well below the threshold of 15% for sodic soils (De Villiers *et al*., 2003).

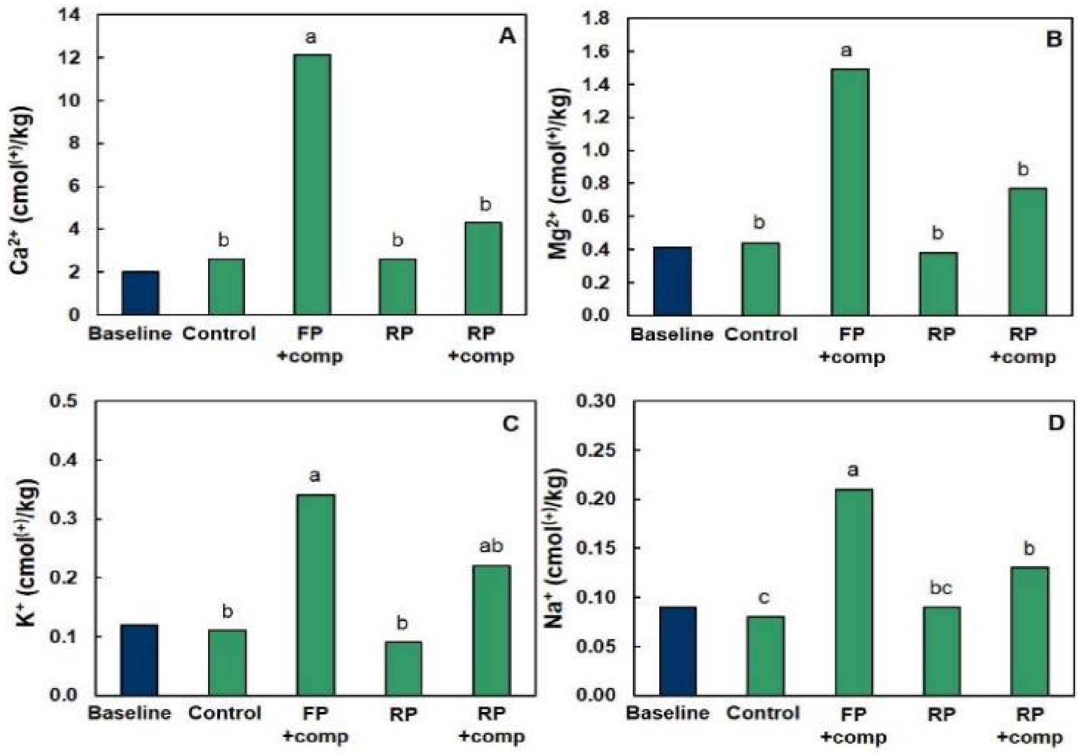

Figure 4.23. The effect of tillage and compost on the extractable cations in the 0-90 cm soil depth in the work row compared to the control and the baseline value. For each variable, columns designated by the same letter do not differ significantly ($p \leq 0.05$).

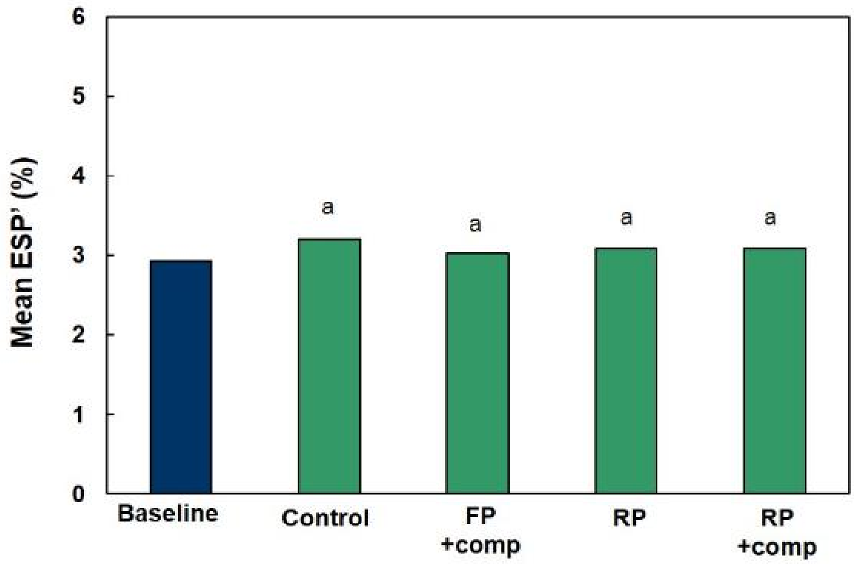

Figure 4.24. The effect of tillage and compost on the mean extractable sodium percentage (ESP') of the soil (0-90 cm soil depth) in the work row compared to the control and the baseline value. Columns designated by the same letter do not differ significantly ($p \leq 0.05$).

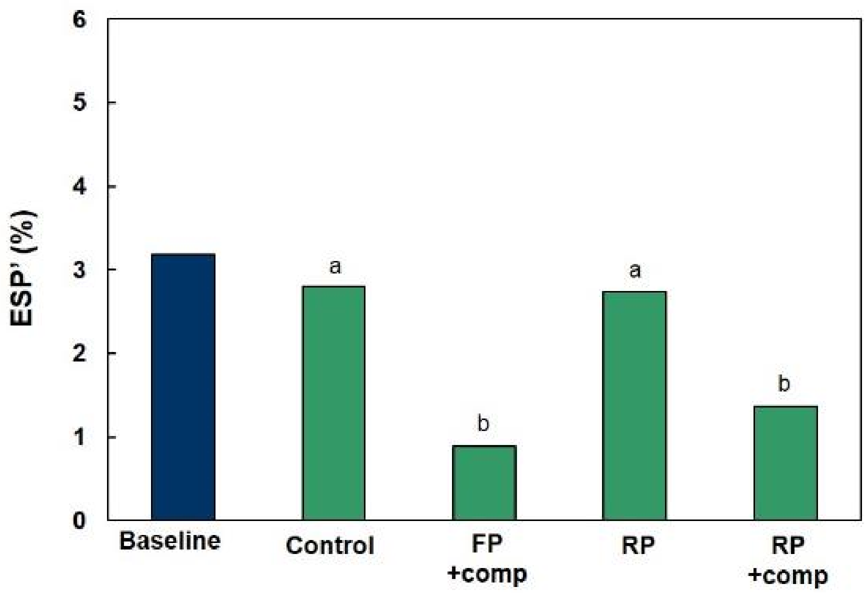

Figure 4.25. The effect of tillage and compost on the extractable sodium percentage (ESP') of the soil (0-15 cm soil layer) in the work row compared to the control and the baseline value. Columns designated by the same letter do not differ significantly ($p \leq 0.05$).

4.3.5.5 Iron

The mean iron (Fe^{2+}) content in the 0-90 cm soil layer was higher in the soil of FP+comp and RP+comp compared to the control and RP (Fig. 4.26). This was to be expected since the compost contained a high level (13848 mg/kg) of Fe^{2+} (Table 4.3). The Fe^{2+} content in the 0-15 cm soil layer was highest where compost had been incorporated with the furrow plough, compared to the control and other treatments, but the soil of RP+comp also had a higher Fe^{2+} content than the control and other treatments (Fig 4.27). In the 15-30 cm soil layer, only the soil of RP+comp had more Fe^{2+} than the control. The tillage and compost treatments had no effect on the Fe^{2+} content below 30 cm. Despite the high Fe^{2+} content where compost had been incorporated, no visual symptoms of iron toxicity, or any other toxicities were observed during the study period. Iron toxicity would only expected under waterlogged or anaerobic conditions where pH levels are low (A. Harding, personal communication).

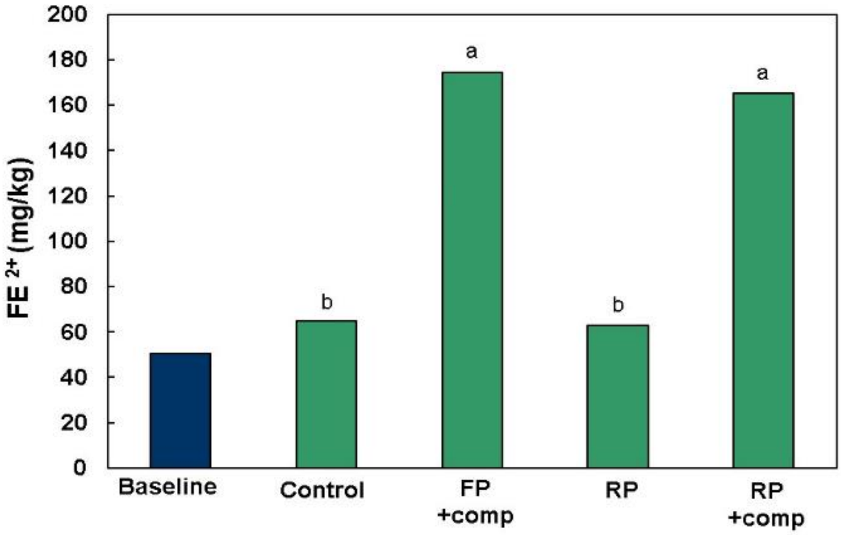

Figure 4.26. The effect of tillage and compost on the mean iron (Fe^{2+}) content of the soil (0-90 cm soil layer) in the work row compared to the control and the baseline value. Columns designated by the same letter do not differ significantly ($p \leq 0.05$).

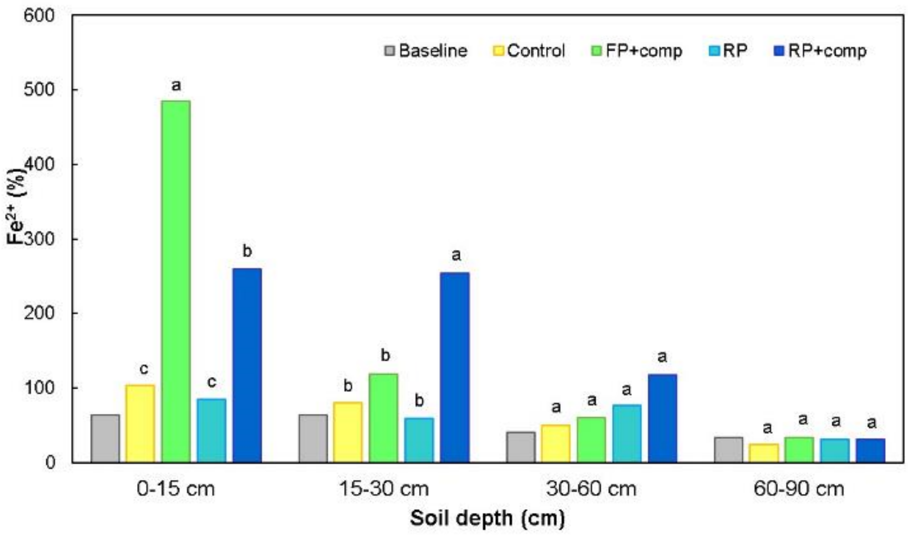

Figure 4.27. The effect of tillage and compost on the iron (Fe^{2+}) content in the 0-15 cm, 15-30 cm, 30-60 cm and 60-90 cm soil layers in the work row. For each depth, columns designated by the same letter do not differ significantly ($p \leq 0.05$).

4.4 Conclusions and recommendations

Compost incorporation with a furrow plough and root pruning actions improved soil conditions on the work row through decreased soil strength and increased water infiltration rate. Root pruning without compost also decreased soil strength but had no effect on water infiltration rate. Soil water content on the grapevine row did not differ between treatments, which suggested limited lateral flow of soil water from the work row to the vine row. However, increased root distribution in the work row may have occurred in response to the improved soil conditions.

When the soil was tilled using a furrow plough and compost incorporated into the work row, the organic C content of the shallow soil layer (0-15 cm) increased substantially, whereas root pruning with compost increased the organic C content to a depth of 30 cm. Given that organic C is one of the organic matter properties associated with higher soil quality, the compost incorporation was successful in improving this aspect of soil quality. The furrow plough with compost increased P and NH_4^+-N in the shallow soil layer and K^+ to a depth of 30 cm. Root pruning with compost increased P in the 15-30 cm soil layer and K^+ in the 0-15 cm soil layer. Root pruning without the addition of compost had no notable effect on soil C, NH_4^+-N, P and K^+ content. The mean extractable calcium, magnesium and potassium increased in response to compost incorporation by means of the furrow plough, whereas extractable sodium increased where compost was incorporated by root pruning as well as by means of the furrow plough. However, further perusal of the data showed that in relation to the other cations, the Na^+ levels were low and the extractable sodium percentage was in fact reduced in the 0-15 cm soil layer in response to compost incorporation. The lower extractable sodium percentage where compost was applied could be attributed to the high Ca^{2+} content in the compost. The combination of the high extractable calcium and the mineralisation of organic material, increased the soil $pH_{(KCl)}$ where compost was applied. The increased pH in response to organic amendments increased the phosphorus content of soil. High levels of Fe^{2+} in the compost resulted in high levels of Fe^{2+} in the 0-30 cm soil layer, but had not effect on the Fe^{2+} content below 30 cm. The high levels Fe^{2+} where compost was incorporated did not appear to have any effect on grapevine health as no visual symptoms of toxicity were observed.

Since soil organic matter is considered an important aspect of sustainable land management systems and the evaluation thereof, results showed that compost incorporation could be considered a sustainable practice where compost composition is regulated and where it is economically viable for a producer to apply. In such cases, it could serve as a nutrient source and reduce the quantity of fertilizer required while enhancing soil physical properties. Results suggest that the older method of organic material incorporation by means of a furrow plough may still be a worthwhile practice where deep soil loosening is not necessary. Where vigour and yield is poor due to compaction, compost incorporation by root pruning in every row could induce a positive aboveground growth and yield response. With the exception of decreased penetration resistance, root pruning without compost incorporation did not enhance soil conditions. While detailed root studies were beyond the scope of this study, they form part of a larger project and are expected to provide valuable information about the nature of the root response to the different tillage and compost treatments. Further investigation into the response of soil physical and chemical properties to different rates of compost would be invaluable to growers where costs are of concern. Monitoring of soil water content on the work row in addition to the grapevine row would be of value in evaluating the grapevine reaction to the treatments.

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Chapter 5

Research results

The effect of root pruning and the furrow plough with compost on grapevine performance and cover crop growth

CHAPTER V: THE EFFECT OF ROOT PRUNING AND THE FURROW PLOUGH WITH COMPOST ON GRAPEVINE PERFORMANCE AND COVER CROP GROWTH

5.1 Introduction

Reasons for poor grapevine performance include unfavourable physical (Van Huyssteen, 1988) or chemical soil conditions, lack of nutrients (Conradie, 1988) and/or water, grapevine age, disease and competition (Morlat & Jacquet, 2003). In some vineyards, variability of grapevine growth, *i.e*. patches of poor performing grapevines within a generally well-performing vineyard, presents challenges for growers. This variability can be difficult to manage as it can either necessitate the costly practice of harvesting of different zones within a vineyard at different times, or it may compromise the overall quality of a vineyard if all grapevines are harvested at once. Above-ground growth is largely determined by the distribution of the grapevine's root system and the conditions at the soil-root interface. Grapevine performance is directly related to root volume and/or distribution (McClymont, 2006).

Management practices that aim to address the causes of underperformance include soil profile modification, soil surface management and the use of various cover crops (Van Zyl & Van Huyssteen, 1983; Linares *et al*., 2014). Under conventional management, a soil's organic carbon (C) outputs are likely to exceed inputs, which is of growing concern due to the potential consequences such as erosion and a decline in overall soil fertility. Intense tillage, loss of soil organic matter (SOM) and low levels of microbiological activity contribute to soil physical degradation (Cass & McGrath, 2005). Organic matter (OM) incorporation is common practice in horticulture but is not widely used in viticulture. Compost is a source of organic matter and plant nutrients. It has been incorporated at planting with varying results (Saayman & Van Huyssteen, 1980) but it is seldom applied to established vineyards. Some of the reported benefits of compost incorporation include improved soil structure and increased water holding capacity, grapevine growth and yields (Ponchia *et al*., 2012; Gaiotti *et al*., 2016). Root pruning is used as a means of growth control in vigorous orchards and vineyards (Giese et al., 2007), as well as a method of "rejuvenating" grapevines with signs of poor growth (Van Zyl & Van Huyssteen, 1987). In the past, the latter practice was relatively popular in South Africa, particularly where soil compaction was a concern (Van Huyssteenl, 1988; Archer, 2011). Root pruning of grapevines by deep ripping has been shown to result in an initial decrease in vegetative growth and yield, followed by increases in canopy size and yield over the long-term, with no effects on berry quality (McCarthy *et al.*, 2010). In contrast, root pruning by deep ripping combined with a permanent cover crop decreased shoot growth and did not affect yield compared to clean cultivation in a flood irrigated Colombar vineyard (Saayman & Van Huyssteen, 1983). However, the variability in grapevine responses to root pruning can be attributed to the timing and method of application, soil moisture at the time of root pruning, as well as the severity of the root pruning action, *i.e.* on one side or both sides of the grapevine (Dry *et al*., 1998). While the furrow plough is not widely used, it is one of the few methods of OM incorporation in viticulture. Traditionally, grapevine prunings were deposited into the trenches created by the furrow plough, followed by a disc action or "oprolploeg" to cover the trench (Van Huyssteen, 1981). However, the practice was not perceived to be particularly beneficial to grapevine growth and yield (Van Huyssteen, 1977). Given the increased variability in rainfall in many of the grape growing regions of South Africa, and current pressures placed on water resources, methods whereby grapevines can be better buffered against severe water deficits or optimized under conditions of limited water are becoming of increasing value to the grape growing industry. The broader benefits of compost are acknowledged in various farming systems, but more knowledge of the correct application of compost and its effects in vineyards is required to enable growers to make informed decisions in their respective situations. Therefore, the aim of this trial was to evaluate the effect of root pruning on grapevine and cover crop performance and to compare two different methods of compost incorporation *i.e.* by means of the furrow plough and by root pruning. Additionally, it serves to ascertain whether or not the practice of creating furrows in the work row for OM incorporation is beneficial for grapevine performance.

5.2 Materials and Methods

5.2.1 Treatments and experiment layout

5.2.1.1 Treatments

Tillage and compost treatments were applied to the vineyard (Table 5.1). The locality of the six replicates is presented Figure 5.1. Details of the viticultural aspects, experimental layout, and soil responses are presented in Chapters IV.

Table 5.1. Tillage and compost treatments applied to the Pinotage/R110 vineyard near Stellenbosch in September 2015.

Treatment no.	Treatment	Description
T1	Control	No tillage
T2	Alt rows FP+comp	Furrows alternate rows, with compost 57 t/ha
T3	All rows FP+comp	Furrows every row, with compost 57 t/ha
T4	Alt rows RP	Root pruning alternate rows
T5	All rows RP	Root pruning every row
T6	Alt rows RP+comp	Root pruning alternate rows, with compost 57 t/ha
T7	All rows RP+comp	Root pruning every row, with compost 57 t/ha

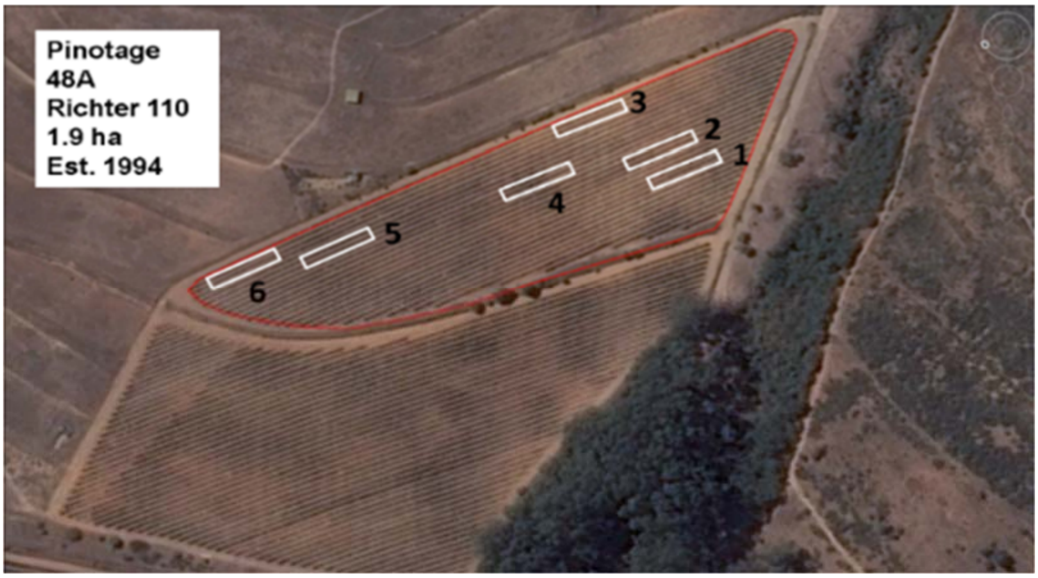

Figure 5.1. Locality of the six replications consisting of four experiment major plots within the Pinotage vineyard on the lower slopes of the Stellenbosch Mountain. Replicates represented lower (3), moderate (1, 2 & 6) and higher (4 & 5) vigour.

5.2.2 Measurements

5.2.2.1 Atmospheric conditions

Details of atmospheric measurements are presented in Chapter III.

5.2.2.2 Grapevine water status

Grapevine water status was quantified by measuring the midday stem water potentials (Ψ_S) in mature leaves on primary shoots using the pressure chamber technique (Scholander *et al.*, 1965) according to the protocol described by Myburgh (2010). Leaves were placed in aluminium bags at least one hour prior to measurement. The Ψ_S was measured in one leaf per treatment plot in three replicates on at least four occasions during the growing season. The measurement dates coincided with major phenological stages. A sharp blade was used to severe the leaf at the base of the petiole before placing the leaf and bag in the pressure chamber within a few seconds. Grapevine water stress was classified according to the thresholds (Table 5.2) described by Myburgh (2011).

Table 5.2. Water stress thresholds for predawn (Ψ_{PD}), leaf (Ψ_L), stem (Ψ_S) and total diurnal (Ψ_{Tot}) water potential in Merlot/99R near Wellington as estimated by Myburgh (2011) from the predawn leaf water potential (Ψ_{PD}) water stress classifications as proposed by Ojeda *et al.* (2002) and Deloire *et al.* (2004).

Class	Water stress	Water potential thresholds			
		(MPa)	(MPa)	(MPa)	(MPa)
I	None	$\Psi_{PD} \geq -0.2$	$\Psi_L \geq -1.1$	$\Psi_S \geq -0.4$	$\Psi_{Tot} \leq 12$
II	Mild	$-0.2 > \Psi_{PD} \geq -0.4$	$-1.1 > \Psi_L \geq -1.4$	$-0.4 > \Psi_S \geq -1.0$	$12 < \Psi_{Tot} \leq 19$
III	Moderate	$-0.4 > \Psi_{PD} \geq -0.6$	$-1.4 > \Psi_L \geq -1.6$	$-1.0 > \Psi_S \geq -1.4$	$19 < \Psi_{Tot} \leq 25$
IV	Strong	$-0.6 > \Psi_{PD} \geq -0.8$	$-1.6 > \Psi_L \geq -1.8$	$-1.4 > \Psi_S \geq -1.6$	$25 < \Psi_{Tot} \leq 29$
V	Severe	$\Psi_{PD} < -0.8$	$\Psi_L < -1.8$	$\Psi_S < -1.6$	$\Psi_{Tot} > 29$

5.2.2.3 Vegetative growth

Grapevines in the experiment plots were pruned in July during dormancy to two-bud spurs and the cane mass per grapevine determined in the field using a hanging balance (Salter, Electro Samson). The pruning weights were recorded for the 2014/2015, 2015/2016 and 2016/2017 seasons to determine grapevine vigour. Pruning mass per plot was converted to tonnes per hectare and the pruning weight per grapevine was divided by the number of canes to obtain an average mass per cane. In the case of this experiment, pruning weight was used as a measure of ‘grapevine vigour’.

5.2.2.4 Yield

Each experiment grapevine was harvested separately by hand in the 2015/16 and 2016/17 seasons. The harvested grapes were weighed in the vineyard using a portable balance (Mettler Toledo, Viper SW, 5 g - 35 kg). The total number of bunches per grapevine were also counted and the yield per experiment plot determined. Yield in kg was converted to tonnes per hectare. The average mass per bunch was calculated by dividing the mass of grapes per grapevine by its number of bunches. In order to calculate the mean number of bunches per grapevine, the total number of bunches per plot was divided by the number of grapevines per plot. At harvest, ten bunches were randomly selected from each plot, harvested and weighed. A representative sample of 20 berries per bunch was collected from both sides of the bunch. Berries were removed by cutting through the pedicel as close to the berry as possible, using scissors. Mean berry weight was measured on a 50-berry sample collected from 10 grapevines in each treatment plot.

5.2.2.5 Berry sampling and analysis

Berry development was monitored several times from véraison until harvest in three of the six major plots. One 50-berry sample was collected from the ten grapevines in each experiment plot. Berries were randomly selected from bunches on either side of the canopy. One berry was selected from the bottom, two from the middle and two from the top of each selected bunch. Analyses of the berries was carried out on the day of sampling. Berry fresh mass (g) and volume (mL) were measured by weighing and water displacement, respectively. The 50-berry sample was crushed using a household handheld liquidizer by three consecutive pulses. The crushed berry slurry was poured through a small kitchen sieve. The skins and pulp were lightly pressed to allow all the juice to move through the sieve. Total soluble solids (TSS) was measured using a digital pocket refractometer (Pocket PAL-1, Atago U.S.A. inc., Bellevue, WA, U.S.A.). Total titratable acidity (TA) and juice pH were measured using an automatic titration device (Metrohm 785 DMP Titrino, Metrohm AG, Herisau, Switzerland).

5.2.2.6 Micro-vinification

During both seasons, four major plots were selected for micro-vinification of grapes from four treatments, namely the control, All rows FP+comp, Alt rows RP and Alt rows RP+comp (Table 5.3). The grapes were micro-vinified at the experimental cellar of the Department of Viticulture and Oenology, Stellenbosch University. The grapes were crushed and destemmed into 50 L plastic drums and juice samples collected for ˚B, titratable acidity and pH. Thirty mg/L SO_2 was added to the crushed grapes. The crushed grapes were inoculated with 30 g/hL of a commercial *Saccharomyces cerevisiae* yeast (ICV-D21, Lallemand). Thirty g/hL Go Ferm Protect (Lallemand) was added to the rehydration water. Twenty-four hours after inoculation, co-inoculation with 0.01 g/L Oenococcus Oeni (Enoferm Alpha, Lallemand) was performed to ensure malolactic fermentation. Fermentation was conducted on the skins at 25 °C and the cap was punched down three times a day. After the sugar had dropped by 5°B (to approximately 20 °B), a nutrient source was added in the form of Fermaid K (Lallemand). The must was fermented down to between 0°B and 5°B and the skins pressed at -1˚B and at 1 Bar. Malolactic fermentation was completed at 20 °C. After the Central Analytical Facility (CAF) at Stellenbosch University, South Africa confirmed that malolactic fermentation was completed by determining malic and lactic acids enzymatically, the wines were racked off the lees and 50 mg/L SO_2 was added. Cold stabilization of the wines took place over 3 weeks at -4 °C before adjusting the free SO_2 to 40 mg/L and botting under screw cap. The bottled wines were stored at 14 °C until they were evaluated in August.

Table 5.3. Wines produced in the 2015/16 and 2016/17 seasons.

Wine	Replicates	Treatment	Description
1	2 & 4	Control	No treatment
2	2 & 4	Alt rows RP	Root pruning alternate rows
3	2 & 4	Alt rows RP+comp	Root pruning alternate rows, with compost
4	2 & 4	All rows FP+comp	Furrows every row, with compost
5	1 & 3	Control	No treatment
6	1 & 3	Alt rows RP	Root pruning alternate rows
7	1 & 3	Alt rows RP+comp	Root pruning every row, with compost
8	1 & 3	All rows FP+comp	Furrows every row, with compost

Clear samples (50 mL) of each wine from both seasons were analysed at the CAF Laboratory at Stellenbosch University. Wines were analysed for volatile acidity (g of acetic acid/L), total acidity (g of tartaric acid/L), malic acid (g/L), lactic acid (g/L), glucose and fructose (g/L), ethanol (% vol) and glycerol (g/L). A FOSS GrapeScan 2000, FT 120 was used to measure the wines (Table 5.3).

5.2.2.7 Red wine colour and total phenolic content

Spectral measures for wines at actual pH and SO_2 level as well as at uniform pH and SO_2 level were carried out. A representative sample of 75 mL was taken from three bottles of each wine made (Table 5.3) to evaluate red colour and total phenolic content by means of spectral measures (Iland *et al*., 2000). The pH of a sub sample of the representative wine sample was determined using a pH meter, and the pH adjusted to 3.5 using 1N HCl or NaOH accordingly. The 25 mL pH-adjusted representative sample and the 50 mL unadjusted wine sample were used for the measurements. Each measurement was allocated three laboratory replicates and, accordingly, six test tubes were marked for this purpose (Fig. 5.2). A micropipette was used to accurately add 2 mL wine to test tubes one and three. Two mL of pH adjusted wine was added to test tubes two, four, and five. Thirty µL of a 25% Na_2SO_5 solution was added to test tubes three and four. The test tubes were mixed using a vortex (Heidolph REAX). Test tube five received 20 µL of a 10% CH_3CHO solution before being mixed, using the vortex. Samples were left to stand for 45 minutes before the spectral measurements were performed. During the 45 minutes standing time, 10 mL 1N HCl and 100 µL of wine was added to test tube six. Test tube 6 was left to stand for three hours before spectral measurements were carried out. All samples were centrifuged in a Digicen 21R (OrtoAlresa) at 13000 rpm for 10 minutes at 15 °C before being measured in the UV/Visible Spectrophotometer (SPECORD 40). Three absorbance readings were taken of representative wine samples to ensure that the instrument provided consistent readings. Samples in test tubes one to five were measured at 420 nm and 520 nm in a 1 mm glass cuvette. These absorbance readings were multiplied by a factor 10, and divided by 1 (width of the cell in mm) in order to determine what the absorbance would have been if measured in 10 mm cuvettes. The absorbance of samples from test tube six was measured at 280 nm and 520 nm in a 1 mm quartz cuvette and was therefore multiplied by the dilution factor of 101 to determine the absorbance of the undiluted sample. The procedure detailed above was carried out on all eight wines from both seasons. The formulae in Table 5.4 were used to calculate the spectral measurements for each wine.

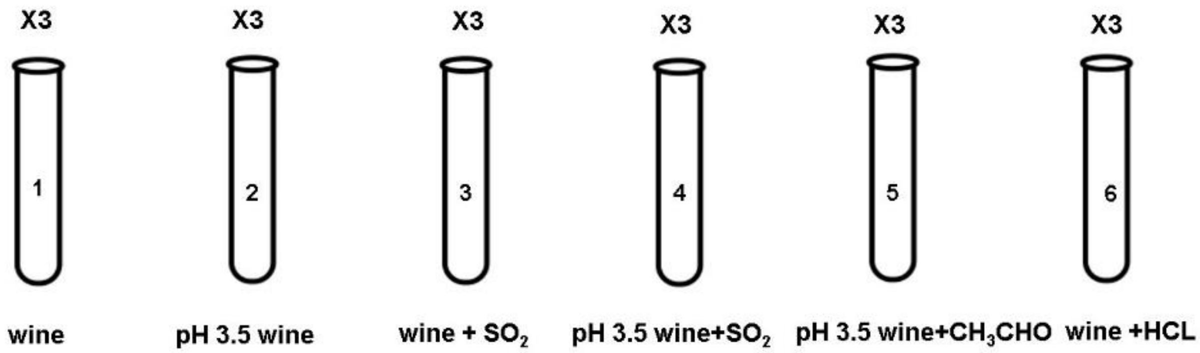

Figure 5.2. Test tubes 1-6 with corresponding replicates.

Table 5.4. Formulae for the calculation of spectral measurements carried out on the wines using the recorded absorbance readings (SASEV, 2003).

Formulae for non-adjusted wine samples	Formulae for pH-adjusted wine samples
Wine colour density = A $_{520}$ + A $_{420}$	Modified wine colour density = (A CH_3CHO $_{520}$ + A CH3CHO $_{420}$) pH 3.5
Wine colour hue = A $_{420}$ / A $_{520}$	Modified wine colour hue = (A CH_3CHO $_{420}$ / A CH_3CHO $_{520}$) pH 3.5
SO2 resistant pigments = A SO_2 $_{520}$	Modified SO2 resistant pigments = (A SO2 $_{520}$) pH 3.5
Total red pigment colour = A HCL $_{520}$	
Degree of red pigment colouration = (A $_{520}$ / A HCL $_{520}$) x 100%	Modified degree of red pigment colouration = (A CH3CHO $_{520}$ / A HCL $_{520}$) pH 3.5 x 100%
Total phenolics = A HCL $_{280}$ - 4	

5.2.2.8 Sensory Evaluation, data analysis and statistics

In August 2016, an informal preliminary tasting by a panel of four members consisting of experts in the field of sensory analysis and viticulture was undertaken to determine whether major differences in aroma and flavour could be detected. Four wines from the 2015/16 harvest were selected for the sensory analysis, namely 1 (Control of plots 2 & 4), 2 (Alt Rows RP of plots 2 & 4), 5 (Control of plots 1 & 3) and 6 (Alt Rows RP of plots 1 & 3). All eight wines from the 2016/17 harvest underwent sensory evaluation in July 2017 (Table. 5.3). A panel of 14 industry professionals, mostly winemakers, evaluated the wines' aroma and flavour attributes in duplicate, in a single session. The Pick-K attributes method, a variant of Check-All-That-Apply (CATA), was selected to evaluate the wines. The Pick-K method provides panellists with a list of sensory characteristic from which they are required to select the K attributes that appropriately describe the product (Valentin *et al.*, 2012). Depending on the number of K attributes listed, the Pick-K method highlights the main sensory characteristics of the wine, whereas the CATA method enables a more complete sensory description (Valentin *et al.*, 2012). In this case, the panel was required to select a maximum of five descriptors within the following major categories: fruit, floral, vegetative, spicy, toasted wood and animal in addition to rating the intensity of sweetness, sourness, body, bitterness, astringency and aftertaste. This method is appropriate for the rapid evaluation of large sample sets. The sensory evaluation took place under controlled conditions where light and temperature were regulated, and noise and odours eliminated. The wines were removed from storage at 20 °C one day before evaluation. Samples of 25 mL were poured 30 minutes before testing into black (opaque) glasses labelled with random codes and covered with a Petri dish. The wines were randomized according to a Williams Latin-square design and presented monadically, one sample at a time. A 10 minute break in between tastings ensured that fatigue did not interfere with the wine assessments.

Sensory data were captured on paper ballots and entered into Microsoft Excel 2013. Statistical analysis was carried out in Statistica 13 (www.statsoft.com, Statsoft Inc.). Correspondence analysis was used to compare treatments with descriptors that were identified in the wines by the sensory panel.

5.2.2.9 Cover crop measurements

Triticale was sown by hand at a seeding density of *c*. 60 kg/ha in early May 2016. A randomly selected sub-plot of 3.78 m^2 on the work row of each experiment plot was identified and the above-ground vegetative growth was harvested by hand in September 2016. The samples were weighed and oven-dried for 48 h at 70 ºC. Cover crop dry matter production (DMP) was determined after weighing and converted from grams to tonnes per ha. Cover crop samples were also analysed by Elsenberg Agricultural Laboratory for macro- and micro-elements (NH_4^+-N, P, K^+, Ca^{2+}, Mg^{2+}, Na^+, Fe^{2+}, Cu^{2+}, Zn^{2+}, Mn^{2+}, B^{3+}, Al^{3+} & S). The DMP was multiplied by the concentration of the different elements (B) and the percentage surface area covered by the cover crop (*c*. 0.8) to determine the quantities of macro- and micro-elements intercepted by the cover crop. Interception of N, K^+, Mg^{2+} and Ca^{2+} was determined using the following equation:

A = DMP x B x 0.8 x 10 (Eq. 5.1)

Where A is the amount of element intercepted (kg/ha), DMP is the dry matter production (t/ha), B is the plant element concentration (%) and 10 is the conversion factor to obtain kg/ha. The amount of Na^+ and micro-elements intercepted was calculated using the following equation:

A = DMP x B x 0.8 ÷ 1000 (Eq. 5.2)

Where A is the amount of element intercepted (kg/ha), DMP is the dry matter production (t/ha), B is plant element concentration (mg/kg) and 1000 is the conversion factor to obtain kg/ha

5.2.3 Statistical analysis

The data were subjected to an analysis of variance. Least significant difference (LSD) values were calculated to facilitate comparison between treatment means. Means which differed at $p \leq 0.05$ were considered to be significantly different. Statgraphics® was used to fit linear regression models. STATGRAPHICS® version XV (StatPoint Technologies, Warrenton, Virginia, USA).was used for the analyses of variance.

5.3 Results

5.3.1 Atmospheric conditions

Refer to Chapter III for a detailed description of the atmospheric conditions.

5.3.2 Grapevine water status

Generally, winter rainfall stored in the soil together with the rainfall that occurs during the growing season is insufficient to prevent moderate to severe water constraints in dryland vineyards in the Coastal region of South Africa (Van Zyl & Van Huyssteen, 1983). Measurements at the beginning of the 2015/16 season showed that Ψ_S was around -0.44 MPa (Table 5.5) which is the upper threshold for no water constraints (Myburgh, 2011). Before véraison, all grapevines experienced mild water constraints *i.e.* Ψ_S was around -0.88 MPa. One day prior to harvest, Ψ_S ranged from -1.2 MPa to -1.4 MPa, which indicated that the grapevines experienced moderate water constraints at this time. There were no differences in grapevine Ψ_S between any of the treatments and the control on all measurement dates. Mild water stress can be beneficial for berry development, in particular for red wine grapes, as it can limit shoot growth and prevent shading of bunches (Williams *et al.*, 1994). Measurements conducted after flowering (07 Nov) during the 2016/17 season showed that the average Ψ_S was -0.49 MPa and grapevines therefore experienced mild water constraints (Table 5.6). In early December 2016 during berry development, grapevines of all treatments continued to experience mild water constraints (-0.81 MPa). Just prior to harvest, the Ψ_S ranged from -1.4 MPa to -1.49 MPa, which indicated that grapevine Ψ_S had reached the lower threshold for strong water constraints. There were also no differences in cumulative water constraints between the various tillage and compost-amended treatments and the control during both seasons (Figs. 5.3 & 5.4). There was a strong correlation between midday Ψ_S and SWC during both seasons (Fig. 5.5A & B). The lack of differences in grapevine water status between treatments during both seasons was to be expected, since there were no differences in soil water content on grapevine row among the treatments (Chapter IV). Grapevine water status followed a similar pattern during both seasons. Since the vineyard is cultivated under dryland, well-developed root systems clearly supplied adequate water to prevent severe water constraints during ripening, except for the strong water constraints just prior to harvest in 2017. Severe water constraints can inhibit stomatal opening, transpiration and photosynthesis (Van Zyl, 1987). In semi-arid conditions, water availability has been shown to dominate the regulation of berry quality, in terms of berry growth and sugar accumulation, more so than leaf area and fruit load (Santesteban & Royo, 2006).

Table 5.5. Effect of different tillage and compost treatments on midday stem water potential (Ψ_s) in Pinotage/R110 near Stellenbosch during the 2015/16 season.

Treatment[1]	Stem water potential (Ψ_s) (MPa)				
	02 Nov	07 Nov	18 Dec	07 Jan	20 Jan
T1 - Control	-0.45 a[2]	-0.78 a	-0.85 a	-1.36 a	-1.40 a
T2 - Alt rows FP+comp	-0.45 a	-0.73 a	-0.97 a	-1.22 a	-1.38 a
T3 - All rows FP+comp	-0.43 a	-0.73 a	-0.93 a	-1.37 a	-1.40 a
T4 - Alt rows RP	-0.47 a	-0.75 a	-0.90 a	-1.32 a	-1.25 a
T5 - All rows RP	-0.40 a	-0.70 a	-0.82 a	-1.37 a	-1.20 a
T6 - Alt rows RP+comp	-0.44 a	-0.73 a	-0.87 a	-1.29 a	-1.33 a
T7 - All rows RP+comp	-0.41 a	-0.81 a	-0.80 a	-1.24 a	-1.37 a

[1] Refer to Table 5.1 for explanation of the treatments.
[2] Values designated by the same letter within a column do not differ significantly ($p \leq 0.05$).

Table 5.6. Effect of different tillage and compost treatments on midday stem water potential (Ψ_s) in Pinotage/R110 near Stellenbosch during the 2016/17 season.

Treatment[1]	Stem water potential (Ψ_s) (MPa)		
	07 Nov	05 Dec	17 Jan
T1 - Control	-0.52 a[2]	-0.78 a	-1.48 a
T2 - Alt rows FP+comp	-0.47 a	-0.83 a	-1.48 a
T3 - All rows FP+comp	-0.53 a	-0.81 a	-1.49 a
T4 - Alt rows RP	-0.48 a	-0.80 a	-1.44 a
T5 - All rows RP	-0.48 a	-0.82 a	-1.46 a
T6 - Alt rows RP+comp	-0.47 a	-0.83 a	-1.40 a
T7 - All rows RP+comp	-0.45 a	-0.83 a	-1.48 a

[1] Refer to Table 5.1 for explanation of the treatments.
[2] Values designated by the same letter within a column do not differ significantly ($p \leq 0.05$).

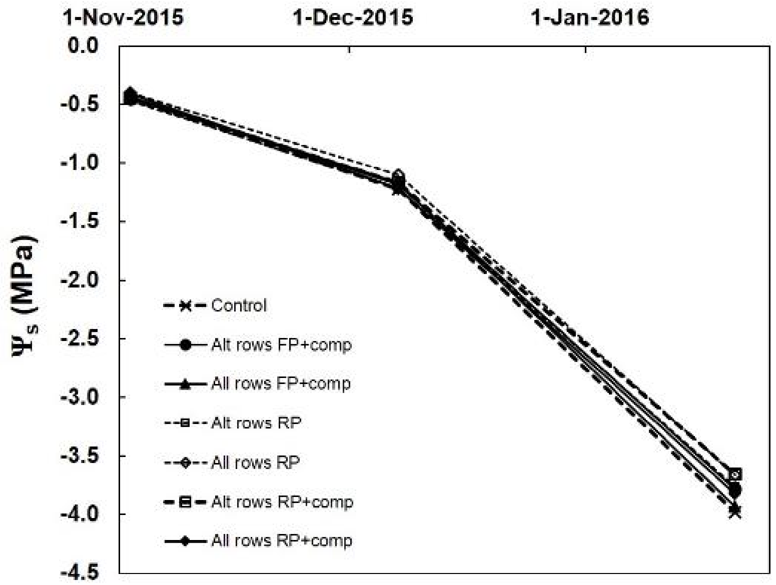

Figure 5.3. Effect of different tillage and compost treatments on cumulative midday stem water potential (Ψ_s) in Pinotage/R110 in a sandy clay loam soil near Stellenbosch during the 2015/16 season.

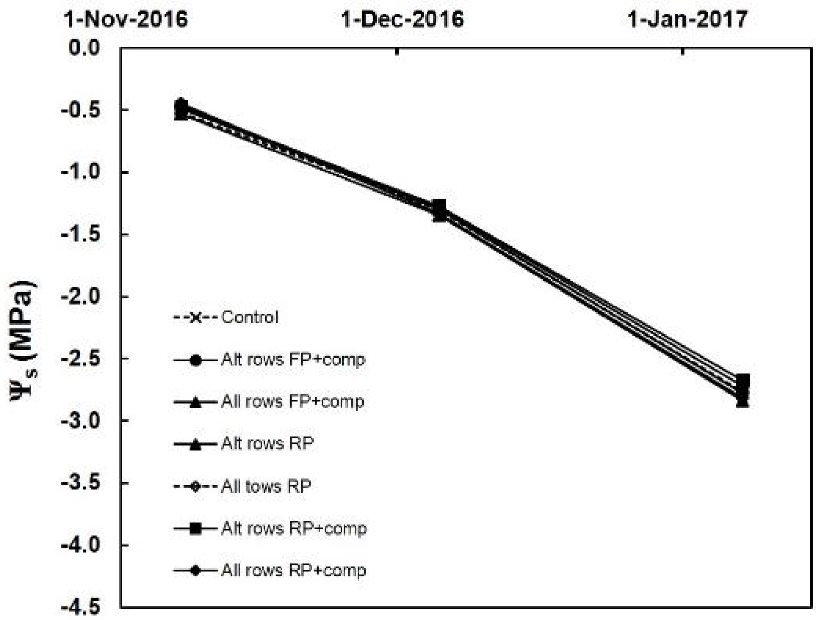

Figure 5.4. Effect of different tillage and compost treatments on cumulative midday stem water potential (Ψ_s) in Pinotage/R110 in a sandy clay loam soil near Stellenbosch during the 2016/17 season.

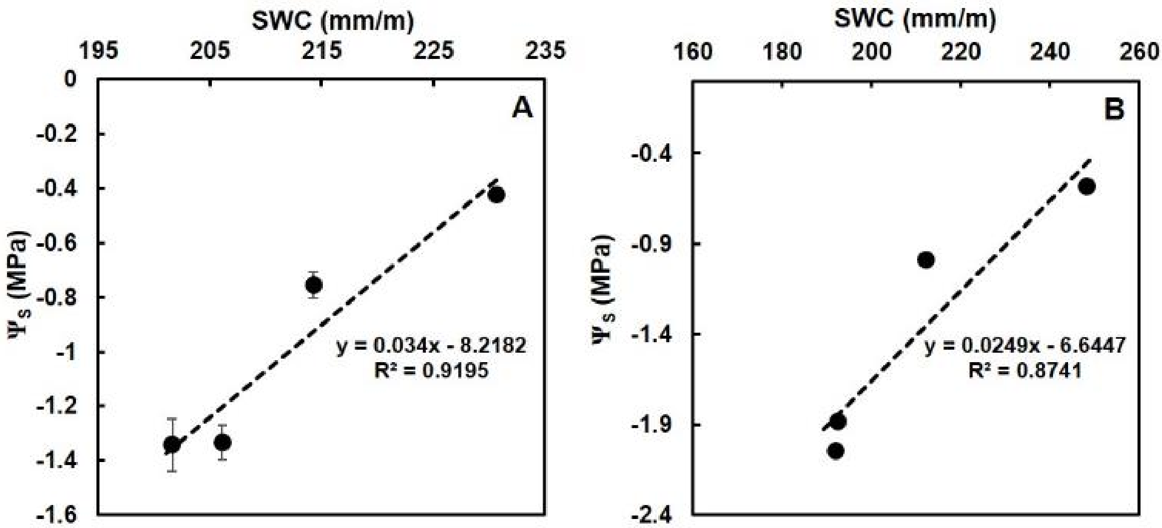

Figure 5.5. The relationship between soil water content (SWC) and midday stem water potential (Ψ_s) during the (A) 2015/16 and (B) 2016/17 season.

5.3.3 Vegetative growth

In July 2016, the mass per cane of All rows RP+comp grapevines was higher than the control, Alt rows and All rows FP+comp, Alt rows and All rows RP grapevines (Fig.5.6). The mass per cane of All rows FP+comp grapevines was also higher than that of the control, Alt rows and All rows RP. In 2017, the mass per cane of All rows RP+comp grapevines was higher than the control, Alt rows FP+comp, Alt and All rows RP, but was not different from the All rows FP+comp and the Alt rows RP+comp grapevines. There were no differences in the number of canes per grapevine between treatments in 2016 and 2017 (Fig. 5.7). In 2016, where compost was incorporated in every row by root pruning, grapevine pruning mass was higher than that of the control grapevines and all other treatments (Fig. 5.8). Where compost was incorporated in every row with the furrow plough, pruning mass was also higher than the control.

In 2017, pruning mass of grapevines under the compost amendment treatments in every row (All rows RP+comp & All rows FP+comp) was higher than that of the control grapevines (Fig. 5.8). Where compost was incorporated in every row by root pruning, the pruning mass was also higher than all other treatments with the exception of the All rows FP+comp treatment. In 2016 and 2017, mass per cane and pruning mass tended to increase where compost had been applied (Alt & All rows FP+comp and Alt & All rows RP+comp). Furthermore, there was a greater vegetative response where compost had been applied in every row (All rows RP+comp & All rows FP+comp). Apart from root pruning in alternate rows without compost, pruning mass in the 2016/2017 season tended to respond to all compost amendment treatments. While grapevines of All rows RP+comp presented the strongest vegetative growth response, vegetative growth of All rows FP+comp grapevines was also higher than the control. The pruning mass was slightly higher in July 2017 compared to July 2016 (Fig. 5.8). This may have been due to limited rainfall that occurred between April and September 2015. Since this difference was observed across all treatments and the control grapevines, it could not be attributed to a delayed response to tillage and compost.

The above-mentioned results indicated a rapid response to tillage and compost incorporation. Similarly, vegetative growth responded positively to inter-row organic amendments in the form of cattle manure (4 t/ha) and crushed pruned vine-wood (4 t/ha) during the first two years of a five year experiment (Gaiotti *et al.*, 2016). A previous study found no clear effect of incorporated organic material on shoot mass and yield, but demonstrated that grapevine above-ground performance was related to effective soil depth (Saayman & Van Huyssteen, 1980). The rate and composition of organic amendments plays a major role in determining the nature of the resulting growth response. High rates of manure amendments can give rise to excess N content, which can result in reduced root development, vegetative growth and yield (Morlat, 2008). The increased above-ground growth response to compost is likely to be linked to soil structural changes, water-holding capacity (Ramos, 2017), increased soil volume available for root development (Saayman & Van Huyssteen, 1980), soil organic matter and microbial activity (Gaiotti, 2017). In the current field trial, vegetative growth responded positively during the first two years to the once-off compost application, particularly where it was applied to every row (Fig 5.8). However, vegetative growth did not respond to root pruning without compost during both years. In a previous study, there was a marked decrease in the first year's shoot growth of Sultanina due to root pruning on both sides of the grapevine, but in the following year shoot growth did not differ from the control (Van Zyl & Van Huyssteen 1987).

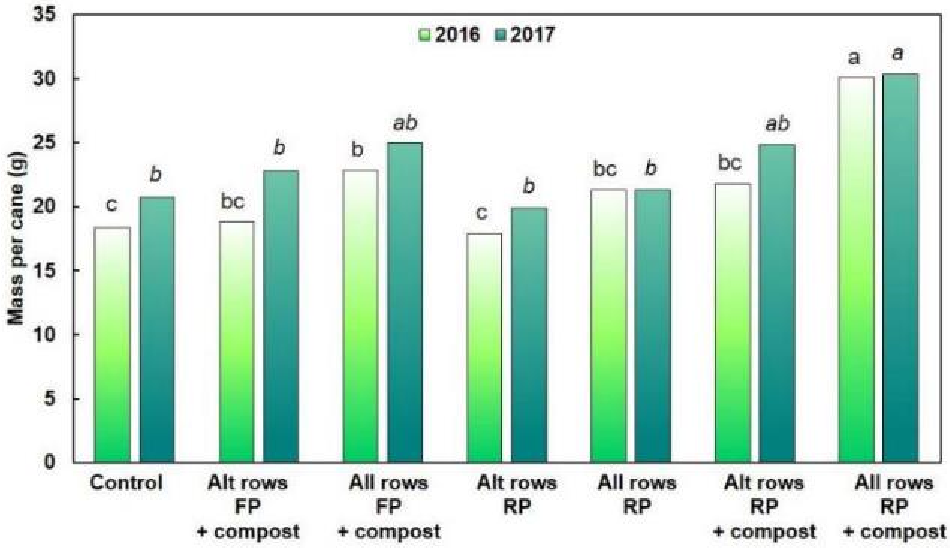

Figure 5.6. The effect of tillage and compost applied in September 2015 on the mass per cane determined at pruning in 2016 and 2017. Columns representing variables within a season designated by the same letter do not differ significantly (p ≤ 0.05).

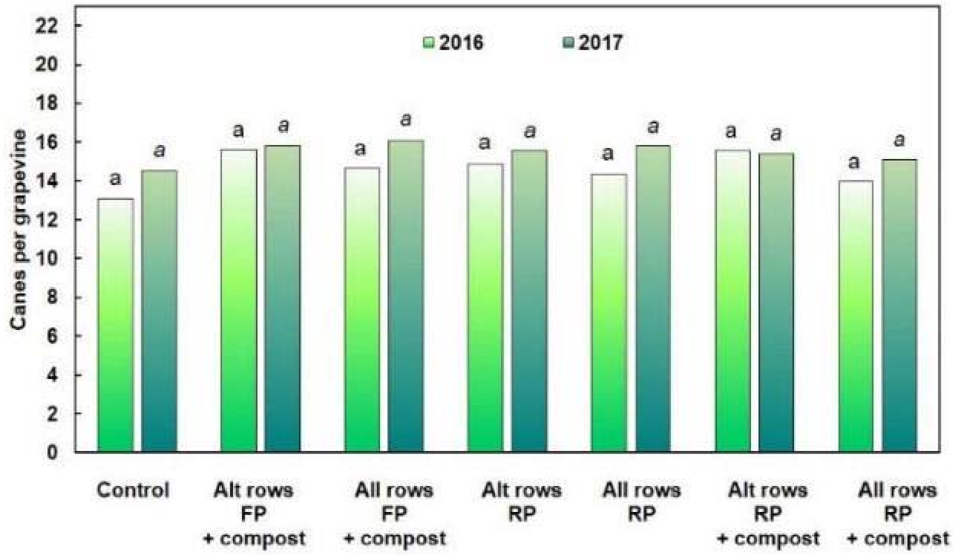

Figure 5.7. The effect of tillage and compost applied in September 2015 on the number of canes per grapevine at pruning in 2016 and 2017. Columns representing variables within a season designated by the same letter do not differ significantly (p ≤ 0.05).

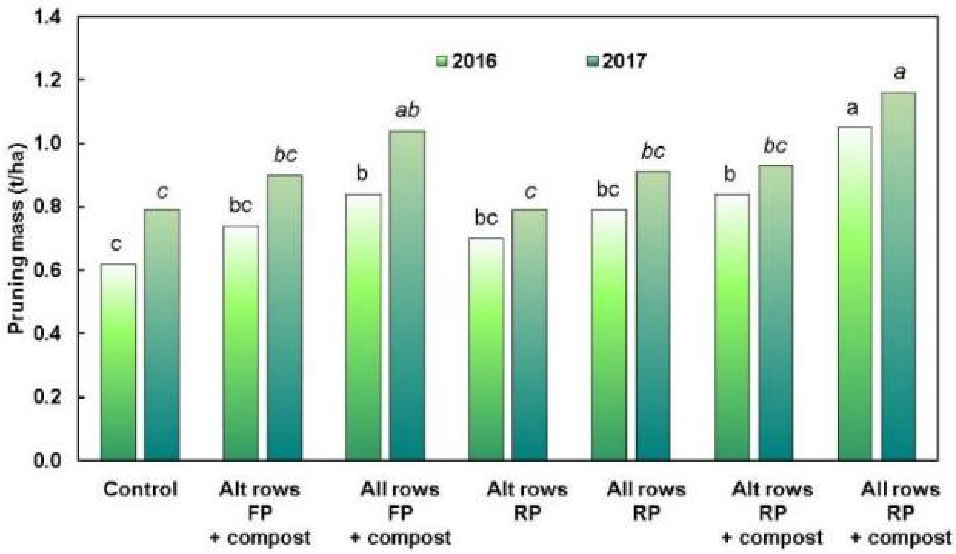

Figure 5.8. The effect of tillage and compost applied in September 2015 on the pruning mass in 2016 and 2017. Columns representing variables within a season designated by the same letter do not differ significantly (p ≤ 0.05).

Figure 5.9. Effect of tillage and compost on grapevine vigour during the growing season in 2016.

5.3.4 Yield

In the 2015/16 season, where compost was incorporated in alternate rows and in every row by means of the furrow plough and root pruning, the yield was higher than that of the control (Fig. 5.10). There were no differences in the yield of All and Alt rows RP grapevines compared to the control. All rows FP+comp and All rows RP+comp grapevines only tended to yield slightly higher than Alt rows FP+comp and Alt rows RP+comp. Where compost was incorporated in every row (All rows FP+comp & All rows RP+comp), the yields were 8.9 t/ha and 9.05 t/ha, respectively, compared to 6.22 t/ha of the control. According to industry guidelines, yields of 0 to 8 t/ha for Pinotage are considered “low” and yields that range from 9 to 16 t/ha can be considered “moderate (Pinotage Association data). In 2017, yield of only All rows FP+comp and All rows RP+comp was higher than that of the control, Alt rows FP+comp and Alt rows RP grapevines (Fig. 5.10). In 2017, the yields of All rows FP+comp and All rows RP+comp were 7.7 t/ha and 7.63 t/ha, respectively, and were about 2 t/ha higher than the control. Therefore, the yield of all compost-amended grapevines responded positively during the first season whereas a positive yield-response was only observed in the grapevines with compost amendment in every row during the second season. Root pruning had no effect on yield during both seasons. Similarly, the yield of Sultanina grapevines in Upington only tended to increase in response to root pruning after two seasons, whether on one side or both sides of the row (Van Zyl, 1984). However, the yield of

Colombar grapevines subjected to annual root pruning in every row was reduced (Saayman & Van Huyssteen, 1983). In an extensive soil management trial carried out in Australia, yield decreased substantially during the first year in response to ripping the entire mid-row soil profile (McCarthy *et al*., 2010). However, yields returned to normal in the third year after ripping and increased compared to the control thereafter. The yield response was related to the extent of root growth in the mid-row before ripping was carried out. Where significant roots were present in the mid-row, ripping resulted in extensive root pruning, which caused in an initial reduction in canopy size and yield.

In 2016, with the exception of All rows RP, grapevines of all treatments had higher bunch numbers compared to the control (Fig. 5.11). In 2017, there were no differences in bunch numbers between treatments compared to the control. Therefore, the treatments where compost was incorporated appeared to improve grapevine fertility as quantified in terms of the number of bunches per grapevine, during the first season only. The bunch mass differed between treatments and the control during both seasons (Fig. 5.12). In 2016, the bunch mass of all compost treatments (Alt rows & All rows FP+comp and Alt & All rows RP+comp) was higher than the control (Fig. 5.12). Bunch mass of grapevines where compost was applied in every row by furrow plough and root pruning was also higher than that of Alt rows RP. The highest bunch mass was found in RP+comp, which was higher than all treatments except All rows RP+comp and Alt rows RP+comp. Although the bunch mass of All rows FP+comp (140 g) and All rows RP+comp (148 g) was higher than the control grapevines (109 g), bunch mass across all treatments was relatively low, compared to values reported for Pinotage/99R in the Breede River Valley (Myburgh, 2011). In 2017 bunch mass followed a similar pattern *i.e.* bunch mass of grapevines where compost was incorporated was higher than the control, but bunch mass of All rows RP was also higher than the control.

During both seasons, bunches of All rows FP+comp and All rows RP+comp had more berries per bunch than those of the control grapevines (Fig 5.13). In 2017, the aforementioned treatments also had more berries per bunch than Alt rows FP+comp and Alt rows RP. The grapevines of Alt rows RP+comp also had more berries per bunch than the control. Since there were no differences in berry mass between treatments and the control during both seasons, the higher bunch mass could not be attributed to berry mass differences (Fig.5.14). The increased yield of grapevines furrow ploughed or root pruned in every row with compost could therefore be linked to increased bunch mass and a higher number of berries per bunch during both seasons. However in the first season, the higher number of bunches per grapevine may also have contributed to the increased yield of All rows FP+comp and RP+comp. The number of bunches per shoot and berries per bunch has been correlated with water stress and N deficiency in during flowering in the preceding season (Guilpart *et al*. 2014). In a long-term experiment on Cabernet franc, differences in grapevine vegetative growth and yield due to various organic amendments were only observed after a 14-year period (Morlat, 2008). Results also indicated that annual incorporation of low rates (2 t/ha) of pruned vine-wood compost resulted in favourable increases in growth and yield, whereas high rates (20 t/ha) of compost comprising manure or mushroom waste, reduced affected grapevine vegetative growth and yield. According to Van Zyl (1987), grapevines with higher crop loads consume more water than those with lower crop loads, but in this instance no differences in grapevine water status were observed. Low yields have been correlated with drier seasons and high water deficits during the growing period, particularly during the early stages, bud break to flowering (Ramos & Martínez-Casasnovas, 2010). The lack of differences in water constraints makes is difficult to provide a clear explanation for improved yields observed in the compost treatments. It is possible that increased nutrient availability, stimulated rot growth and increased vegetative growth allowed the grapevine to bear a higher crop.

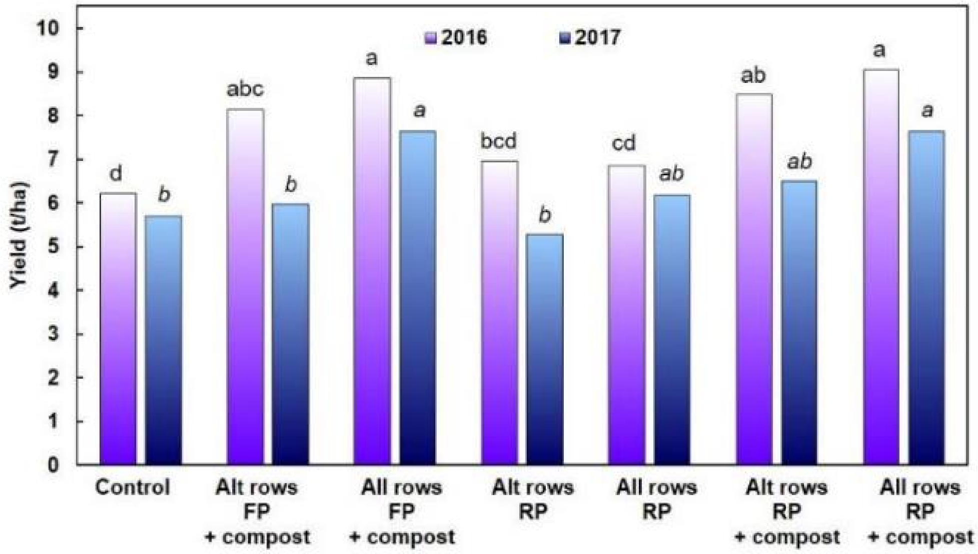

Figure 5.10. The effect of compost and various tillage actions applied in September 2015 on grapevine yield during the 2015/16 and 2016/17 seasons. Columns representing variables within a season designated by the same letter do not differ significantly (p ≤ 0.05).

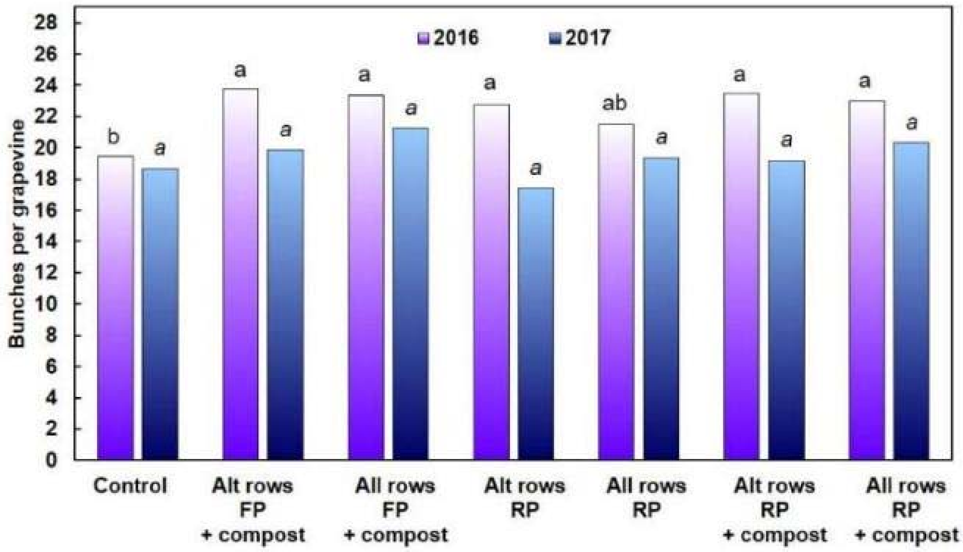

Figure 5.11. The effect of compost and various tillage actions applied in September 2015 on the number of bunches per grapevine (fertility) during the 2015/16 and 2016/17 seasons. Columns representing variables within a season designated by the same letter do not differ significantly (p ≤ 0.05)

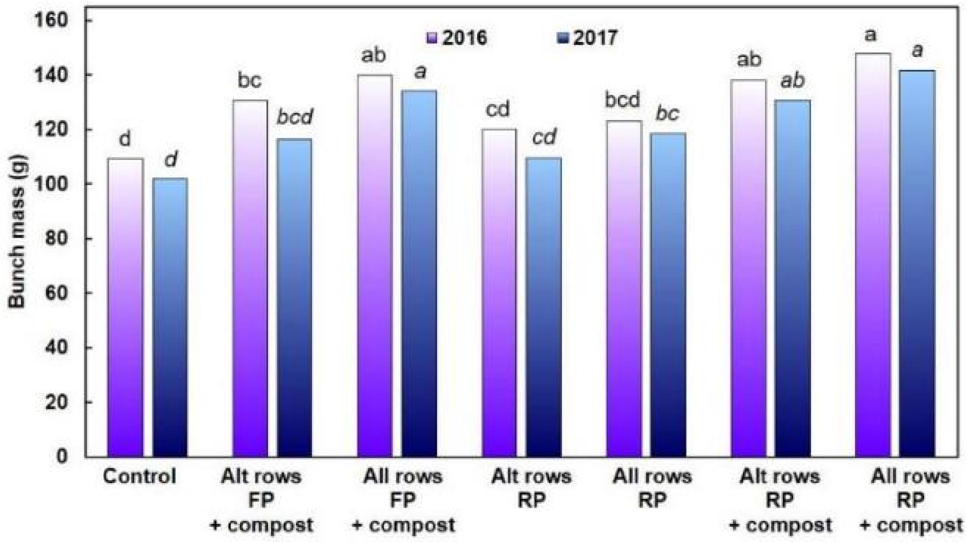

Figure 5.12. The effect of compost and various tillage actions applied in September 2015 on bunch mass during the 2015/16 and 2016/17 seasons. Columns representing variables within a season designated by the same letter do not differ significantly (p ≤ 0.05).

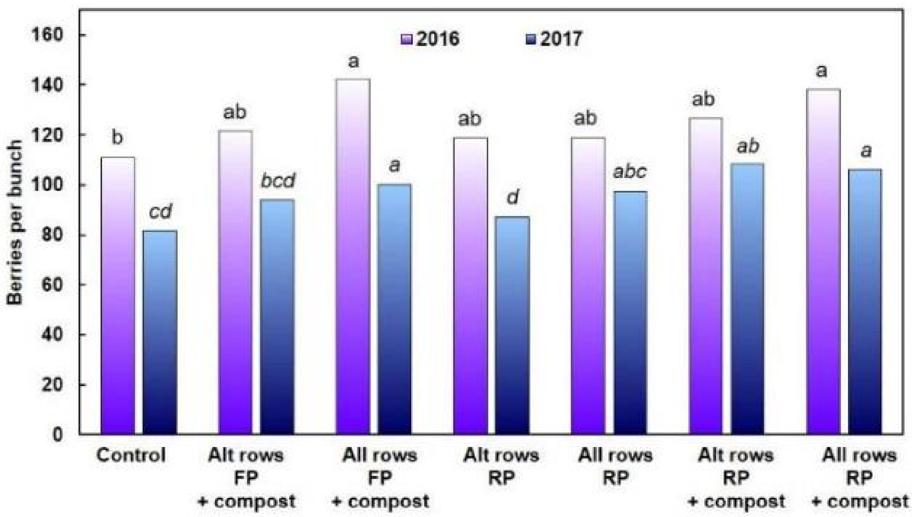

Figure 5.13. The effect of compost and various tillage actions applied in September 2015 on the number of berries per bunch during the 2015/16 and 2016/17 seasons. Columns representing variables within a season designated by the same letter do not differ significantly (p ≤ 0.05).

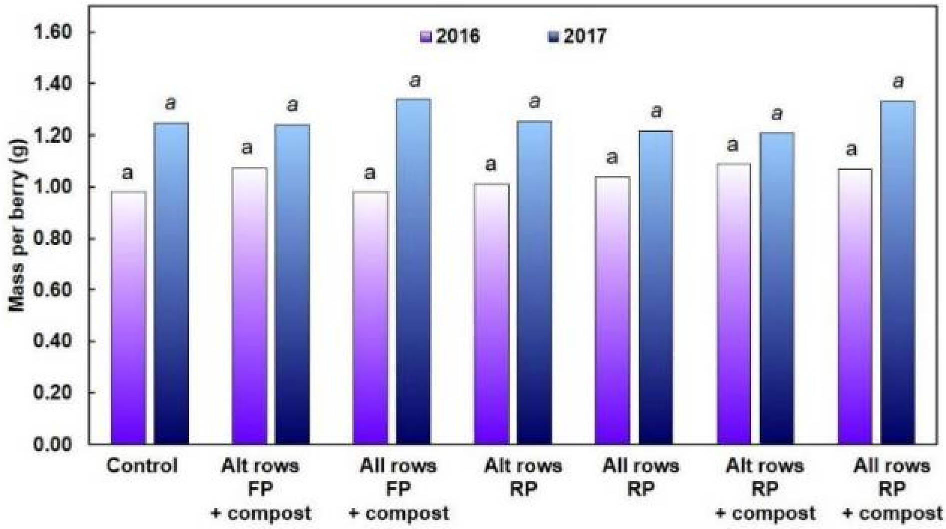

Figure 5.14. The effect of compost and various tillage actions applied in September 2015, on berry mass during the 2015/16 and 2016/17 seasons. Columns representing variables within a season designated by the same letter do not differ significantly ($p \leq 0.05$).

5.3.5 Juice characteristics

During both seasons, the intention was to harvest the grapes at a sugar level of c. 25˚B before berry deterioration occurred. The TSS of grapes harvested during the first season was slightly higher than 25˚B due to a higher percentage of berry damage or dehydration. This may have been related to the particularly high temperatures that occurred in January 2016 (Refer to Chapter III). Seasonal conditions, such as temperature, influence grapevine and berry development (Winkler et al., 1974).

The various tillage and compost-amended treatments had no effect on juice TSS and TA levels during both seasons (Table 5.7). Similarly, ripping the mid-row had no effect on berry composition (McCarthy *et al*., 2010). In 2016, juice of All rows RP+comp berries had a higher pH than the control, Alt rows FP+comp, Alt rows RP and T6 Alt rows RP+comp. Since there were no differences in grapevine water status, berry size, juice TSS and TA between the various tillage and compost-amended treatments and the control, there was no clear explanation for the differences in the juice pH in 2016. In contrast, 5 t/ha compost applied to the grapevine row decreased soluble solids content and increased pH, but had no effect on acidity (Ponchia et al., 2012). In 2017, there were no differences in juice pH. High juice pH can result from shading due to excessive vegetative growth, which is often related to soil water content, soil type and nutritional status. Alternatively, weathering of the organic material may have brought about a flush of K in the soil during the first season only, resulting in increased K uptake by the roots. In this case, the lack of differences in grapevine water status, SWC on the grapevine row and other berry quality parameters suggests the latter option may be responsible. Apart from the juice pH in the first season, the overall berry and juice quality did not respond to compost application or tillage during both seasons. Berry volume and sugar content did not differ between treatments and the control during both seasons. The mean sugar content per berry was 273.8 ± 5.8 mg/mL and 239.5 ± 5.5 mg/mL in the 2015/16 and 2016/17 season, respectively. Compost and tillage did not affect the sugar content during both seasons (data not shown).

Table 5.7. The effect of furrow plough (FP), root pruning (RP) and incorporation of compost (comp) on total soluble solids (TTS), total titratable acidity (TA), pH and berry volume of Pinotage grapes measured near Stellenbosch during the 2015/16 and 2016/17 seasons.

Season	Control (T1)	Furrow plough + comp[1]		Root pruning		Root pruning + comp	
		Alternate rows (T2)	All rows (T3)	Alternate rows (T4)	All rows (T5)	Alternate rows (T6)	All rows (T7)
				Harvest date			
2015/16				21 January 2016 (26-28 ˚B)			
2016/17				19 January 2017 (23-25 ˚B)			
				TSS (˚B)			
2015/16	27.8 a[2]	27.1 a	26.8 a	27.5 a	28.3 a	26.8 a	26.9 a
2016/17	24.0 a	24.3 a	23.0 a	24.7 a	23.4 a	24.1 a	23.7 a
				TA (g/L)			
2015/16	6.42 a	5.86 a	6.0 a	6.01 a	5.97 a	5.81 a	6.05 a
2016/17	7.63 a	7.24 a	7.79 a	7.27 a	7.54 a	7.54 a	7.68 a
				pH			
2015/16	3.81 bc	3.80 c	3.93 ab	3.81 bc	3.88 abc	3.85 bc	4.0 a
2016/17	3.27 a	3.33 a	3.47 a	3.52 a	3.36 a	3.49 a	3.42 a
				Berry volume (cm^3)			
2015/16	0.89 a	0.96 a	1.03 a	0.92 a	0.95 a	0.98 a	0.97 a
2016/17	1.22 a	1.20 a	1.22 a	1.13 a	1.15 a	1.13 a	1.23 a

(1) Refer to Table 5.1 for explanation of the treatments.
(2) Values designated by the same letter within a row do not differ significantly ($p \leq 0.05$).

5.3.6 Micro-vinification

5.3.6.1 Wine chemical composition

Wine acidity and fruit flavour expression, colour, protein and microbial stability are strongly influenced by wine pH. Due to the complex nature of wine and the interactions between various compounds during the winemaking process, an ideal pH does not exist, but generally a pH above 3.8 to 4.0 is considered unfavourable for wine quality. Mean wine pH was 3.53 ± 0.06 and 3.28 ± 0.02 in the 2015/16 and 2016/17 seasons, respectively. The different treatments had no effect on the wine pH, except for a tendency towards higher pH where compost was applied in the first season only (data not shown). Since pH levels were still relatively low regardless of the increase, no problems during the winemaking process would be expected. The mean wine TA was 6.28 ± 0.48 g/L and 6.48 ± 0.13 g/L in the 2015/16 and 2016/17 seasons, respectively. The different treatments had no effect on the wine TA, except for a tendency towards lower acidity where compost was applied in the first season only (data not shown). The higher pH combined with the slightly lower TA measured in the wines of these treatments could be a result of shading due to increased vegetative growth which may have resulted in increased K^+ in the berries (Iland, 1989). Shading also lowers berry temperature which slows malic acid respiration, resulting in higher malic acid, lower pH and higher TA. The higher pH and lower TA combination can occur when the effects of leaf shading dominate the effects berry shading, resulting in decreased photosynthesis and increased K^+ transport to the berries. The grapevine compensates for inefficient sugar accumulation by transporting more K^+ to the berries to maintain cellular turgor. Alternatively, a flush of K^+ may have occurred in the soil of the compost treatments in the first season, as a result of weathering of the organic material. A subsequent increase in root uptake of K^+ may have resulted in increased berry K^+ in those grapevines where compost was incorporated, particularly in every row, due to availability of K^+ as well as increased demand from the higher vigour. In 2017, the pH of all wines was slightly lower than in 2016, and the TA was slightly higher. Although vegetative growth was higher overall in the 2016/17 season compared to the 2015/16 season, and FP+comp and RP+comp in all rows had higher vegetative growth than the control, there were no differences in pH and TA between the treatments. The difference in pH and TA between seasons is likely to be a result of harvesting the grapes at a lower sugar level in the 2016/17 season.

Mean wine malic acid was 0.65 ± 0.11 g/L and 0.45 ± 0.03 g/L in the 2015/16 and 2016/17 seasons, respectively. The malic acid concentrations of the wines were comparable between treatments and the control (data not shown). The lactic acid was 0.45 ± 0.12 g/Land 0.85 ± 0.04 g/L in the 2015/16 and 2016/17 seasons, respectively. The lactic acid content did not differ between treatments (data not shown). Malic acid concentration is affected by ambient temperature *i.e*. higher temperatures increase the rate of L-malic acid respiration during véraison (Volschenk *et al*., 2006). Dense canopies can also stimulate L-malic acid accumulation due to shading of bunches (Archer & Strauss, 1989). Despite higher vigour levels in the compost treatments, malic acid levels were not affected by the treatments. During malolactic fermentation, dicarboxylic L-malic is converted to monocarboxylic L-lactic acid, resulting in an increased pH and decreased perception of acidity (Jackson, 2008). Mean volatile acidity was 0.65 ± 0.11 g/L and 0.60 ± 0.02 g/L in the 2015/16 and 2016/17 seasons, respectively. The volatile acid content of the wines was not affected by the tillage and compost treatments during both seasons and did not exceed the sensory threshold value of 0.7 g/L (Jackson, 2008) (data not shown).

The mean wine glucose content was 1.39 ± 0.34 g/L and 0.34 ± 0.12 g/L in the 2015/16 and 2016/17 seasons, respectively. The mean wine fructose content was 1.24 ± 0.06 g/Land 0.94 ± 0.08 g/L in the 2015/16 and 2016/17 seasons, respectively. During both seasons, the tillage and compost treatments had no major effect on glucose and fructose levels with the exception of the control wine which tended to have a higher glucose content than the tillage and compost treatments in 2016 (data not shown). However, it is possible that alcoholic fermentation did not complete in this case. The glycerol level in all the wines was relatively high and was 11.77 ± 0.26 g/L and 10.38 ± 0.29 g/L in the 2015/16 and 2016/17 seasons, respectively. The tillage and compost treatments had no effect on the glycerol levels in the wines (data not shown). Glycerol is a by-product of alcoholic fermentation and influences wine mouthfeel and viscosity. Yeast strain, fermentation temperature and juice sugar levels all influence glycerol production.

Mean ethanol content was 14.92 ± 0.65% and 13.83 ± 0.33% in the 2015/16 and 2016/17 seasons, respectively. The different treatments had no effect on the ethanol content of the wine (data not shown). Since the grapes were harvested at a slightly higher sugar level in the 2015/16 season, the ethanol content in the wines of the first season was higher.

5.3.6.2 Red *wine* colour and total phenolic content

Mean wine colour density (OD) was 9.0 ± 1.82 and 14.88 ± 0.81 in the 2015/16 and 2016/17 seasons, respectively. The different treatments had no effect on the wine colour density with the exception of the treatments where compost was incorporated (All rows FP+comp & Alt rows RP+comp) which only tended to reduce wine colour density in the first season (data not shown). Colour density ranges suggested by Du Toit (2008) indicate that all the wines of the first season were medium coloured, *i.e*. wine colour density values were between 6 and 10 OD, and those from the second season were deeply coloured *i.e*. the mean wine colour density was above 10 OD. Wine colour is affected by pH and sulphur dioxide, as well as grapevine canopy development and climatic factors before and during ripening.

Wine colour hue is the ratio between the absorbance measured at 420 nm, which quantifies brown polyphenols, and absorbance at 520 nm, which quantifies red anthocyanins. The wine colour hue was 0.67 ± 0.06 and 0.41 ± 0.01 in the 2015/16 and 2016/17 seasons, respectively, which was slightly lower than values reported for a dryland Pinotage vineyard in the Swartland region (Muller, 2017). Wine colour hue did not differ between treatments (data not shown). Wine colour hue increases with wine age and various threshold values have been proposed. However, most recently Du Toit (2008) suggested that that young wines usually have a colour hue of 0.5 to 0.7, whereas colour hue of older wines ranges from 1.2 to 1.3.

The modified wine colour density (OD) was 12.42 ± 1.93 and 13.88 ± 0.66 in the 2015/16 and 2016/17 seasons, respectively, and followed a similar pattern to that of wine colour density. Where compost was incorporated, modified wine colour density tended to be lower but only in the first season (data not shown). The modified wine colour hue was 0.52 ± 0.01 and 0.44 ± 0 in the 2015/16 and 2016/17 seasons, respectively. The various tillage and compost treatments had no effect on modified wine colour hue (data not shown).

The concentration of SO_2-resistant pigments (OD) was 2.16 ± 1.04 and 1.89 ± 0.30 in the 2015/16 and 2016/17 seasons, respectively. Where compost was incorporated by means of the furrow plough and root pruning, the concentration of SO_2-resistant pigments tended to be slightly lower (data not shown). The level of modified SO_2-resistant pigments followed the same trend and was 0.94 ± 0.20 and 1.74 ± 0.28 in the 2015/16 and 2016/17 seasons, respectively. The level of SO_2-resistant pigments measured in a wine is in indication of the percentage of red coloured pigments which are resistant to bleaching by sulphur dioxide. High values for SO_2-resistant pigments indicates a higher degree of pigment polymerisation and colour stability. In the case of the wine produced from grapevines of the two compost treatments (All rows FP+comp and Alt rows RP+comp), the percentage of red coloured pigments resistant to bleaching tended to be lower than that of the control and root pruning during the 2015/16 season only (data not shown). In a recent study, Pinotage wines produced from lower vigour non-irrigated grapevines had higher amounts of SO_2-resistant pigments (Muller, 2017). The marginally higher colour density and SO_2-resistant pigments measured in the wines of the control and root pruning treatment without compost in the current trial, may have been related to the lower level of vegetative growth observed in these treatments. However, since this trend in response to compost was only observed in the first season, no long term effects on wine quality were expected.

The mean total red pigment (OD) of the wine was 24.24 ± 0.65 and 32.63 ± 1.32 in the 2015/16 and 2016/17 seasons, respectively. The different treatments had no effect on the total red pigment level of the wines (data not shown). The mean anthocyanin content of the wine was 498.51 ± 98.31 mg/L and 981.11 ± 71.70 mg/L in the 2015/16 and 2016/17 seasons, respectively. The different treatments had no effect on the anthocynanin content of the wines, with the exception of the compost treatments which tended to produce wines with slightly lower anthocyanin contents in the first season (data not shown). The anthocyanin content of the wines was lower in 2015/16 than 2016/17. Anthocyanins are extracted from the skin. The position of their equilibria, which is sensitive to pH and SO_2, is largely responsible for red wine colour (Somers & Evans, 1974). Anthocyanin content of the wines was higher in the 2016/17 season compared to the 2015/16 season. This could be attributed to the lower pH of the wines in the 2016/17 season. Under dryland conditions, high water stress at pea-size has been associated with increased anthocyanins and total phenolics in berry skins (Koundouras *et al.,* 2006). The mean phenolic content (OD) of the wine was 53.55 ± 3.76 and 56.61 ± 4.32 in the 2015/16 and 2016/17 seasons, respectively. The total phenolic content of the wine was not affected by tillage or compost during both seasons (data not shown). Red wine colour and mouthfeel are a function of phenolic composition of berries (Rossouw & Marais, 2004).

The wines of the 2016 season in particular, were highly variable in their phenolic and colour composition. The slight differences in values for wine colour density, anthocyanins and SO_2-resistant pigments within seasons could be attributed to a shading effect of bunches where increased vigour occurred in response to tillage and compost. The tendency towards reduced colour which was observed in the wines of the compost-amendment treatments in the first season, was not observed in the second season. Therefore, no major long-term effects on wine colour are expected where compost was incorporated.

5.3.7 Sensory analysis

In 2016, wines of the control and root pruning without compost treatments were selected for sensory evaluation. The 2016 sensory data were analysed using correspondence analysis, in which Dim 1 and Dim 2 explained 53.6 % and 33.6 % of the variance, respectively (Fig. 5.15A). As for the wine chemical analyses, there was substantial variability in the sensory characteristics of the wines. A separation is seen in along Dim 1, where the wines of the control and root pruning treatments from two plots in the vineyard differ from those made from another two plots. This is an expression of spatial variability within the vineyard. The control and Alt rows RP treatments of replicate 1 were dominated by dark, ripe fruit, spicy and savoury attributes. Replicate 2 of the control had more pronounced jam and dried grass characters, with some red fruit. The wine of the Alt rows RP treatment of replicate 2 was dominated by dark fruit, red fruit and violet. Except for the Alt rows RP treatments of the two different plots, there was no separation between samples, which indicated that the treatments had no major effect on the sensory characteristics of the wines that were evaluated. The treatments also had no effect on the sweet, sour, bitterness, astringency attributes as well as the length after taste (data not shown).

In 2017, sensory evaluation was carried out on the wines of four treatments namely control, All rows FP+comp, Alt rows RP and Alt rows RP+comp. In the 2017 correspondence analysis graph constructed from the sensory data, Dim 1 and Dim 2 explained 37.7 % and 21.3 % of the variance, respectively (Fig. 5.15B). Variation could be seen between the different replicates of certain treatments as well as between the treatments themselves. The wines of the control and root pruning treatments from replicate 1 were characterised by higher levels of herbaceous and humus/earthy descriptors, with smaller amounts of black currant and solvent/chemical descriptors. The wine of the control from replicate 2, was characterised by banana, raspberry, meaty, savoury cherry and leather attributes. Where compost was incorporated with the furrow plough, regardless of replicate, more of the raspberry, cherry, blackberry, savoury, meaty, leathery descriptors were perceived, with some violet, prune and oakwood. The grapevines that were exposed to root pruning with compost produced wines that were higher in cherry, blackberry, savoury, raspberry characters as well as tobacco, plum, chocolate and blackcurrant. The root pruning treatment of replicate 2 appeared to produce wines that did not differ much from the wines of the compost treatments. None of the wines differed in their expression of sweetness, sourness, bitterness, body and length on the palate (data not shown). The wines of the root pruning treatments, with and without compost, differed in astringency from the wines of the control and furrow plough at a 10% significance level, *i.e.* the wines of the root pruning treatments tended to be slightly more astringent than the wines of the control and furrow plough. There was no explanation for these differences. Given the variability between treatments and the fact that wines spanned the sensory space, no clear differences in the sensory profiles of the wines resulting from tillage and compost could be ascertained. An increase in the number of replicates per treatment may have enabled better differentiation between treatments.

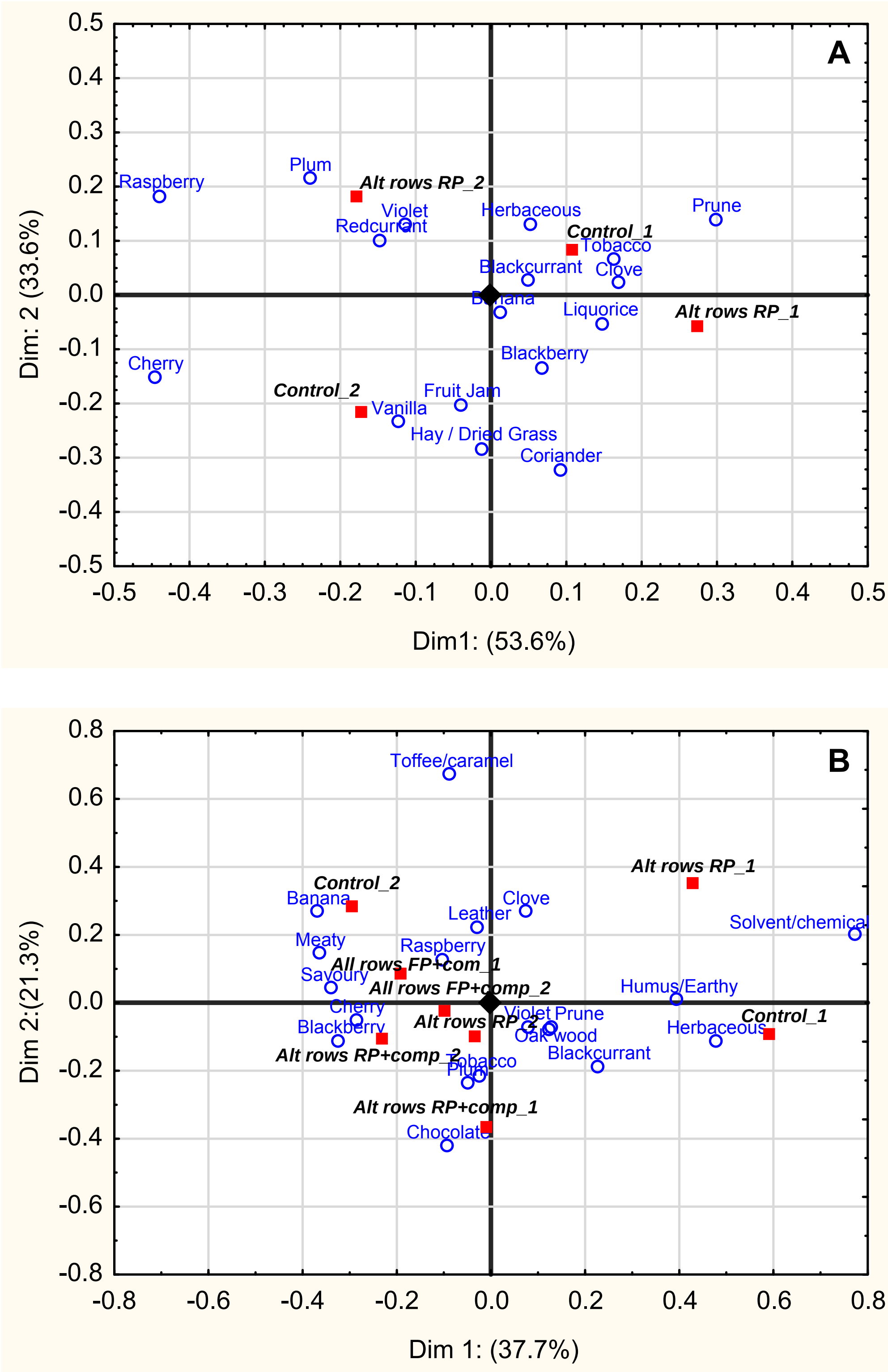

Figure 5.15. Correspondence analysis of the sensory data for the wines of the (A) 2015/16 and (B) 2016/17 seasons.

5.3.8 *Triticale* cover crop

5.3.8.1 Dry matter production

The DMP of the *triticale* cover crop, as measured in September 2016, was higher than that reported by Fourie (2007) for *triticale* and lower than that reported for irrigated Oats L. cv. *Pallinup* on a sandy soil in Rawsonville (Fourie *et al.*, 2014). Cover crop growth responded to compost application as seen in the increased DMP of the treatments where compost was incorporated using the furrow plough (FP+comp) and the root pruning (RP+comp) in September 2016 (Fig.5.16). The DMP of the control was approximately 1.3 to 1.4 t/ha lower than that of the FP+comp and RP+comp treatments, respectively (Figs. 5.17 & 5.18). There was no difference in DMP between the RP and control treatments. It could therefore be concluded that the compost was responsible for the enhanced cover crop performance, likely due to a combined effect of nutrient supply and enhanced soil physical properties. While increased cover crop growth could present increased competition for soil water and nutrient resources under dryland conditions, chemical control before bud break would be expected to negate these concerns. In a cover crop trial, grapevine vegetative growth was stimulated by mineralisation of organic matter after incorporating the crop residue (Ripoche *et al.*, 2011). Since vegetative growth and yield increased where compost was incorporated using the furrow plough and root pruning, and no differences were found in grapevine water status, it can be inferred that the enhanced cover crop did not compete with the grapevines under the prevailing conditions. Cover crop DMP was also strongly positively correlated with water infiltration rate (Fig. 5.19). Cover crop roots create biopores or channels, which facilitate water movement and storage. Cover crops have also been associated with increased inocula of mychorizal fungi in the soil (Galvez *et al*. 1995). Symbiotic relationships between arbuscular mychorizal (AM) fungi and most plant roots aid in water and nutrient uptake. Under Mediterranean conditions, it was demonstrated that cover crop growth improved soil quality through increased porosity, infiltration rate and OM contribution, compared to bare soil management by tillage or herbicide (Linares *et al*., 2014).

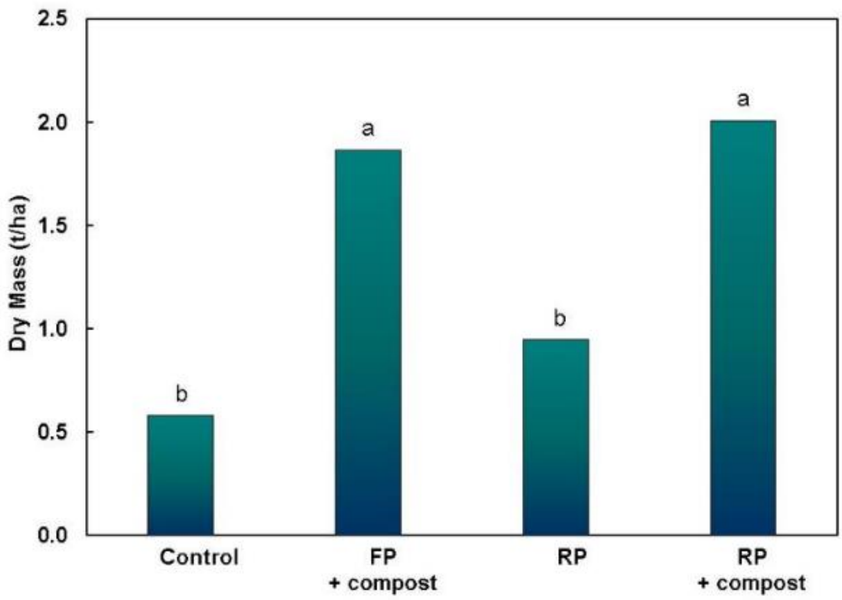

Figure 5.16. Effect of different cultivation practices on total dry matter production (DMP) of the *tricicale* cover crop growing in a Pinotage/R110 vineyard near Stellenbosch during the 2016/17 season. Columns designated by the same letter do not differ significantly ($p \leq 0.05$).

Figure 5.17. Visible effects of furrow plough plus compost (FP+comp) root pruning (RP) and root pruning plus compost (RP+comp) on cover crop growth compared to the control before bud break in 2016

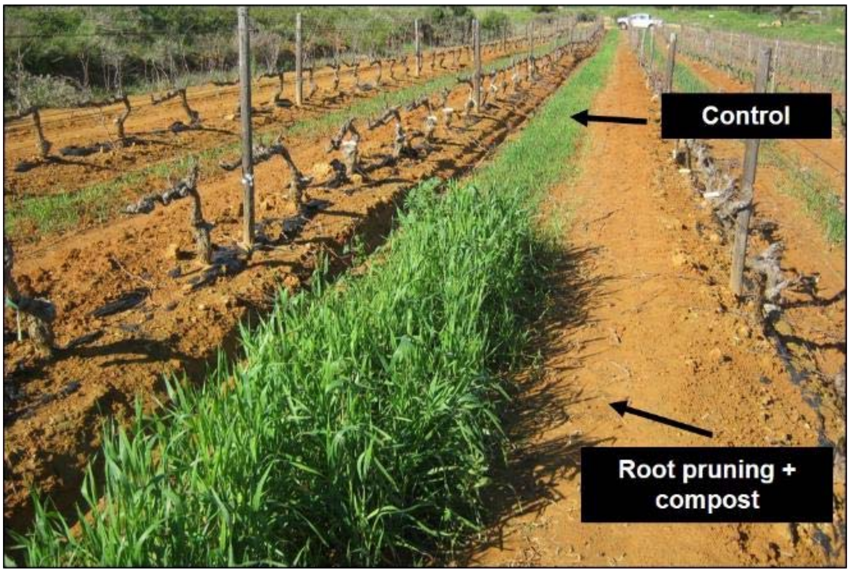

Figure 5.18. The effect of root pruning with compost on cover crop performance compared to the control before bud break in 2016.

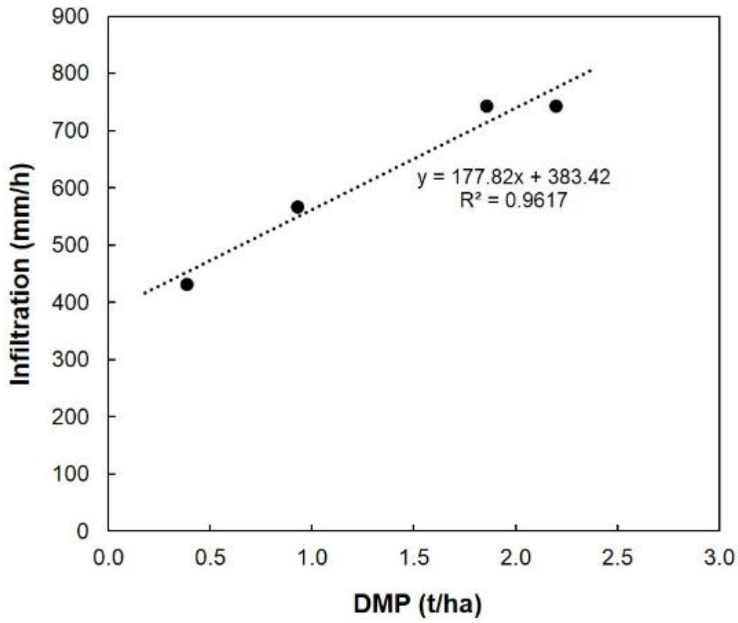

Figure 5.19. Relationship between cover crop dry matter production (DMP) in September 2016, and water infiltration rate on the work row in June 2017.

5.3.8.2 Nutrient interception

The cover crop of the control and RP treatment had a higher N concentration than the treatments where compost was added, namely the FP+comp and RP+comp treatments (Table 5.8). The P, K^+, Ca^{2+} and Mg^{2+} concentrations of the cover crop did not differ. The estimated amount of N removed from the soil by the cover crop of the FP+comp and RP+comp treatments was higher compared to the control (Table 5.9). The amount of N removed by the cover crop in the RP treatment did not differ from the control and the FP+comp treatment. The amounts of P and K^+ removed from the soil by the cover crop in the compost treatments (FP+comp & RP+comp) was higher than that of the control and RP treatment. The Ca^{2+} removed by the cover crop was highest in the RP+comp treatment compared to the control and RP treatment. The Ca of the FP+comp treatment was also higher than the control. The Mg^{2+} intercepted followed a similar pattern to the P and K^+. The Mg^{2+} taken up by the cover crop in the RP+comp and the FP+comp treatments was higher than the control and the root pruning treatments. Root pruning without compost did not have an effect on the quantity of Mg^{2+} removed from the soil. Given that the concentrations of macronutrients did not differ, except in the case of N, it appeared that the differences in the amount of macronutrients intercepted was driven by the increased DMP of the treatments where compost was incorporated. Although the amount of N removed from the soil was higher in the treatments where compost had been incorporated, particularly the RP+comp treatment, grapevine vegetative growth was higher in those treatments, as observed in the pruning mass in July 2017. Therefore the N removed from the soil by the cover crop did not negatively affect grapevine vegetative growth as quantified by pruning mass. Since cover crops are normally left to decompose, no negative long term effects on vegetative growth would be expected.

Table 5.8. Macronutrient concentrations (%) of the cover crop harvested in September 2016.

Macronutrient (%)	T1 - Control	T2 &T3 - Furrow plough + comp	T4 & T5 - Root pruning	T6 & T7 - Root pruning + comp
Nitrogen (NH_4^+-N)	1.30 a[(1)]	0.79 c	1.02 ab	0.93 bc
Phosphorous (P)	0.19 a	0.23 a	0.17 a	0.20 a
Potassium (K^+)	1.25 a	1.31 a	1.24 a	1.31 a
Calcium (Ca^{2+})	0.21 a	0.15 a	0.19 a	0.21 a
Magnesium (Mg^{2+})	0.11 a	0.09 a	0.09 a	0.10 a

[(1)] Values designated by the same letter within a row do not differ significantly ($p \leq 0.05$).

Table 5.9. Estimated amounts of macronutrients (kg/ha) intercepted by the cover crop harvested in September 2016.

Macronutrient (kg/ha)	T1 - Control	Furrow plough + comp	Root pruning	Root pruning + comp
Nitrogen (NH_4^+-N)	4.93 c[(1)]	11.75 ab	7.73 bc	14.51 a
Phosphorous (P)	0.81 b	3.24 a	1.17 b	2.82 a
Potassium (K^+)	5.75 b	19.28 a	9.50 b	21.42 a
Calcium (Ca^{2+})	0.89 c	2.16 ab	1.46 bc	3.35 a
Magnesium (Mg^{2+})	0.48 b	1.12 a	0.69 b	1.54 a

[(1)] Values designated by the same letter within a row do not differ significantly ($p \leq 0.05$).

5.4 Conclusions and recommendations

Tillage and compost incorporation had no effect on grapevine water status during both seasons. This was verified by the lack of differences in soil water content on the grapevine row. Grapevines developed strong water constraints only just prior to harvest in January 2017. Under the prevailing conditions, this suggests that deep root systems enabled grapevines to access deeper soil water reserves during the season, thereby preventing sever water constraints and the negative effects thereof. Despite the absence of variation in water stress due to compost, grapevine vigour and yield responded positively to the compost and various tillage practices during both seasons.

Results showed that deep root pruning without compost provided no significant benefits in terms of increased vegetative growth. However, pruning mass of grapevines increased when compost was applied in the mid-row. Compost consistently had the greatest effect on pruning mass when it was applied in every row by means of the furrow plough and in every row during the deeper root pruning action. The higher pruning mass appeared to be a function of higher mass per cane. The abovementioned vigour responses were probably related to improved soil conditions for better root colonisation and uptake of water. Root pruning did not seem to have a positive effect on grapevine vegetative growth and yield. However the degree of root regeneration in the loosened soil may have been affected by the substantially lower rainfall during the study. The particularly dry conditions in 2015 may have left inadequate soil water reserves to allow for enhanced root development. However, where compost was incorporated during the root pruning action, growth and yield increased over two consecutive seasons. The same improvement in grapevine growth and yield was observed where compost was incorporated in furrows. Under the given prevailing conditions, root pruning in every row with compost did not provide significant additional benefits to growth and yield compared to the root pruning in alternate rows with compost.

Tillage and compost did not affect wine quality in terms of the basic chemical parameters as well as colour and phenolic characteristics. However, there was a slight tendency for wines of the compost treatments to exhibit less colour than the wines of the control and root pruning treatments, but only in the first season. Wines of the compost treatments tended to encompass fewer unfavourable sensory attributes than those of the control and root pruning.

Compost, regardless of the method of incorporation, enhanced cover crop growth. Both the furrow plough and root pruning treatments with compost incorporation resulted in lush cover crop growth, which did not adversely affect grapevine performance. The improved cover crop performance would be expected to further influence soil structure and SOM content. Taking into account all of the abovementioned responses, compost incorporation at a rate of 57t/ha by means of a furrow plough or by root pruning, can be recommended for grapevines under dryland conditions for the improvement of vigour and yield, where soil compaction and limited infiltration is a concern. Root pruning without compost did little to improve the above-ground performance of grapevines under the given conditions and can therefore not be recommended for the upliftment of poor performing grapevines in the short term. Since the results take into account only the first two seasons after the various tillage and compost treatments were applied, it is possible that there may be further responses in terms of yield and growth in the long term. While detailed root studies were beyond the scope of this study, they would be of value in providing a comprehensive understanding of the grapevine response to the tillage and compost.

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Chapter 6

General Conclusions and Recommendations

CHAPTER VI: GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 The effects of mulch on infiltration rate, soil water content and grapevine responses

Results showed that the application of compost mulch on the grapevine row to a thickness of 16 cm had no effect on soil water content to a depth of 90 cm compared to the bare soil. While greater fluctuations in soil water content occurred in the 0-30 cm layer, the treatments did not differ with respect to soil water content over the two seasons. However, water infiltration rate increased with mulch thickness, *i.e.* the highest infiltration rate was observed in the soils under the thicker mulches. Nevertheless, the thicker mulches, *i.e.* 8 cm and 16 cm, appeared to intercept rainfall when relatively small events occurred. Given the abnormally low rainfall in 2015, 2016 and 2017, the mulch was not effective in maintaining a higher soil water content on the grapevine row compared to bare soil. Had ‘normal’ rainfall conditions prevailed, or the occurrence of heavier rainfall events been more frequent, increased infiltration rates may have increased soil water content under the thicker mulches. Grapevine water constraints were also not affected by compost mulch, regardless of the thickness. This was to be expected since soil water content was not affected by compost mulch. In contrast, vegetative growth and grapevine yield responded positively to mulch thickness over the two seasons. Fine root development observed in the shallow soil layers under the mulches could have contributed to the growth response by allowing for improved nutrient absorption. It must be noted that quantification of the root systems was beyond the scope of the study, but is part of an ongoing study. Since water constraints did not differ in response to mulch thickness, improved water uptake was not considered to have contributed to the improved growth and yield. After two seasons, the 8 cm mulch had weathered to a thickness of 3 cm, whereas the 16 cm mulch had weathered to a 6 cm layer. Visual observation indicated that the compost consisted of fine material which explained the degree of weathering after two years.

6.1.2 Improving grapevine performance through tillage and organic matter incorporation

Where compost was incorporated by the furrow plough and root pruning, infiltration rate was higher than the control. Root pruning without compost only tended to increase infiltration rate. Since higher infiltration rates are expected to reduce water loss by runoff, an increase in the amount of water entering the soil of the compost-amended treatments is anticipated. However, the tillage and compost treatments had no effect on the soil water content on the grapevine row. It would seem that there was limited lateral flow of water from the work row to the grapevine row. After two years, the furrow plough with compost and root pruning with and without compost, reduced penetration resistance up to 15 cm and 45 cm, respectively. The penetration resistance in the soil of the control exceeded the 2000 kPa threshold for inhibited root growth at a depth of 12 cm. The soil loosening action of the root pruning with compost is expected to allow for improved root development to a greater depth than the furrow plough treatment, although the furrow plough treatment may have encouraged root development between the tractor wheel tacks to a depth of 15 to 20 cm. It was also noted that during the penetration resistance measurements, soil water content on the work row was higher in the 10-30 cm soil layer of the furrow plough with compost treatment compared to the control and other treatments. Root pruning per *se* had no effect on the soil chemical status, but decreased compaction. Where compost was added, the soil pH increased, probably due to the high amount of calcium in the compost and the dissolution of organic acids present in the organic material. The compost also tended to increase magnesium, potassium and sodium as well as organic carbon and phosphorous in the soil, particularly in the shallow soil layers. The potassium and phosphorous could be a source of nutrients to the grapevines, while the organic carbon influences the accumulation of soil organic matter. In addition to its contribution to the pH buffering of soils and the encouragement of beneficial microbial populations, organic matter influences the availability of nutrients such as nitrogen, phosphorous and sulphur. Although the amount of sodium in the soil increased, the extractable sodium percentage was in fact reduced in the 0-15 cm soil layer, due to the high amount of calcium. The extractable sodium percentage was also well below the threshold where sodicity problems would be expected. The absence of visual symptoms of toxicity indicated that the high iron content measured in the 0-30 cm soil layer where compost was added appeared not to induce iron or any other toxicities in the grapevines.

Under the prevailing conditions, root pruning did not seem to have a positive effect on grapevine vegetative growth and yield. Given that the rainfall during the study was appreciably lower than the long term mean, in 2015 in particular, the degree of root regeneration in the loosened soil may have been affected as well as the subsequent grapevine responses. However, where compost was incorporated during the root pruning action, growth and yield increased over two consecutive seasons. Likewise, where compost was incorporated in furrows, it also had a positive effect on growth and grapevine yield. Under the prevailing conditions, root pruning in every row with compost did not provide significant additional benefits to growth and yield compared to the root pruning in alternate rows with compost. Apart from the slightly higher pH and lower colour in the wines of the compost treatments in the first year, juice and wine quality characteristics were not affected by any of the tillage or compost treatments. The higher potassium content in the soils measured two years after the compost was applied appeared to have had no effect on juice and wine quality. Cover crop growth also responded positively to the addition of compost. However, the enhanced cover crop performance did not appear to compete with the grapevines. Since the cover crop residue is left in the vineyard, decomposition and mineralisation of this residue would further improve organic matter and nutrient accumulation in the soils where cover crop dry matter production was high.

6.2 Recommendations to the industry

6.2.1 Mulching

A compost mulch thicker than 8 cm is unlikely to have a positive effect on infiltration rate but in the case of this study, did improve grapevine growth and yield. Since the compost mulch did not have an effect on soil water content, it cannot be recommended as a water conservation practice per *se*, but would prevent poor grapevine growth and yield losses under particularly dry conditions. The grapevine growth and yield benefits may have been more pronounced had the mulch been applied as a full surface but this would be an extremely costly practice and can therefore not be recommended. Compost consisting of a large portion of fine material appears to be more susceptible to weathering. Therefore, coarser material such as wood chips may enhance its longevity. Where compost is used as a mulch, it should be well prepared and analysed before application to the vineyard to ensure no toxicities will occur. The pH may be increased with lime application to reduce the exchangeable sodium content of the compost if it contains large amounts of manure, which can result in a high sodium content. Mulches can be expensive, particularly when they consist of mature compost which may need to be transported to the farm. Where it is possible to source other organic materials from nearby localities, the practice may be more economically viable. Growers could purchase mulch material, i.e. in the form of chips, from government programmes such as Working for Water, thereby supporting clearing of invasive alien species as well.

6.2.2 Tillage and compost

In vineyards with patches of poor grapevine growth, compost incorporation with a furrow plough or during a root pruning action with an excavator could boost grapevine performance while improving limiting soil physical properties. Since root pruning with compost in every row did not provide major additional benefits to grapevine performance, incorporation of 57t/ha compost in alternate rows during root pruning would be sufficient to improve growth and yield in a vineyard where compaction is of concern, particularly terraced vineyards. In vineyards where bare soils have led to surface crusting, infiltration in the work row can be improved by compost incorporation by means of a furrow plough or root pruning. Although compost incorporation with the furrow plough was effective in improving grapevine growth and yield, the deeper tillage action of the excavator would have loosened a larger volume of soil and distributed the compost to deeper layers, encouraging root development throughout the soil profile. Where root pruning is applied, it is important that it be carried out to a depth of at least 60 cm. Measurement of the penetration resistance revealed that in the case of this study, the effective root pruning depth was only *c*. 45 to 50 cm. Before root pruning is carried out, it is also important to ascertain whether there is root growth between the tractor wheel tracks. If not, the soil should be loosened across the entire work row surface, but only in alternate rows. It is also important to determine whether poor growth is in fact the limiting factor whether grapevines are underperforming. If a chemical toxicity or deficiency is the cause of poor above-ground performance of grapevines, tillage and compost will not necessarily address the problem. Although it is recommended that root pruning be carried out during the post-harvest period, in the case of this study it was carried out in spring due to the lack of precipitation after harvest in 2015. The results from this study suggest that root pruning can be done after the harvest or in spring and in some dryland vineyards the soil may be easier to work in spring.

Considering the results of the two trials, it suggests that where compost is available to the grower, it may be more effective to address poor grapevine performance with compost incorporation rather than an organic surface mulch on the grapevine row, particularly in the case of sloped or terraced vineyards in heavier soils. In dryland vineyards, or where water resources are limited, mulching up to 16 cm on the grapevine row is expected to buffer the grapevine against drought conditions or reduce yield losses during dry seasons.

6.3 Future research

6.3.1 Mulching

Further research on different organic materials for mulching and their respective rates of application are required to develop economically viable practices that growers can implement. While the soil microbial interactions are complex, there is no doubt their role in successful grapevine cultivation is crucial. Current knowledge of the specific microbial populations responsible for the various soil biological processes should be used to identify the ideal composition of mulch material for mulches that enhance encourage favourable microbes.

6.3.2 Tillage and compost

From an economic point of view, it is important to determine the lowest rate at which compost should be applied in order to achieve positive growth responses and improved soil conditions. It would be beneficial if compost nutrient composition could be adjusted to provide adequate nutrients in the correct proportions required for growth. The fact that compost can only be thoroughly incorporated with an excavator between vineyard rows, is a benefit above ripping with a single tine ripper or wiggle plough. However, a comparison between the efficacy of the latter implements, as well as a cost evaluation of root pruning with an excavator should be carried out. Although quantification of the root response was beyond the scope of this study, it forms part of a larger study and will be completed after the third season. A quantification of root regeneration will be useful in understanding the grapevine responses to the various tillage and compost treatments. In future tillage and compost studies, a more frequent quantification of soil water content on the work row will provide more information on the water holding capacity of the soil after tillage and compost has been applied. In the case of this trial, installing neutron probe pipes on the work row would have been impractical. The effect of compost and cover crop growth on aggregate stability, porosity and microbial activity would be useful information for growers. The extent to which cover crops compete with grapevines for water and nutrients in different soils and climatic conditions will be important to help growers carry out management practices to suit their conditions. Future research should also focus on identifying cover crops that can be grown full surface and re-establish by itself on the grapevine row, particularly on slopes where mulch is unfeasible.